MAYA NUMERATION, COMPUTATION, AND CALENDRICAL ASTRONOMY

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The following article is divided into seven sections: I. Introduction; II. Numeration and Notation; III. Calendar, Chronology, and Computation; IV. The Venus Calendar; V. Eclipse Reckoning; VI. Numerology; VII. A Time Perspective.

I. INTRODUCTION

The civilization known to archaeologists as Classic Maya flourished in the lowlands of southern Mexico, Guatemala, Belize, and western Honduras from the late years of the third century to the end of the ninth century of our era, according to most estimates. This area is dotted today with the architectural remains—in ruins except where recently reconstructed—of the numerous administrative and ceremonial centers of that civilization. The societies that erected and occupied these centers may be described as primitive kingdoms and incipient city-states. Their rulers took on the classic characteristics of "divine kings." They caused monuments to be erected in their commemoration and for the affirmation of their pedigree. A related priestly class attended to their needs for mythological charter and supernatural sanction. Among those in priestly occupations were the sky-watchers and the experts in numeration and the calendar. Scribes and artists, some of them with great sensitivity for line and composition, were in courtly service. It is difficult to see how the temples, pyramids, and palaces of these centers could have been erected without some form of coerced labor. There is evidence of wars of conquest and there are records of the taking of high-ranking prisoners; a warrior class and a military organization are to be presumed. There is some evidence of alliances by marriage between ruling families of different centers, or between major centers and satellites. The fortunes of the centers varied as first one and then another rose to prominence and dominating influence. The autochthonous development of this civilization came to an end during the ninth century when, one after another, the Classic Maya kingdoms collapsed. The abandonment of their centers was concomitant with influences—political, cultural, and military—emanating from the Mexican highlands to the west. The ensuing "Mexican" period, or "early postclassic" of Toltec domination, lasted until about the end of the twelfth century, by which time its foreign Nahua-speaking elite appear to have become culturally and linguistically assimilated to the Mayan subject populations. During the "late postclassic," from the thirteenth to the sixteenth centuries, concentrations of political power and "high" culture were absent from the central lowlands, where the monuments of the earlier civilization had fallen into ruin and their sites were reclaimed by the forest. Meanwhile to the north in the peninsula of Yucatan there arose a state or federation with centralized control, with lingering but faded Mexican impress, and lacking most of the excellence that had characterized the culture of the classic period in the central lowlands. This lasted for something over two centuries, until the overthrow of its capital city of Mayapan. Sixty years later the Spaniards arrived, conquered, and consolidated their rule at least in the temporal domain, while somewhat more slowly and less securely in the spiritual. Today in these areas there live some two and a half million speakers of about thirty different Mayan languages, assimilated in varying degrees to Spanish Catholic culture, but yet conserving much that is anciently Mayan.

Our interest here is in the attainments of the Maya astronomers, numerators, and calendar priests of the classic and postclassic periods. Information on that subject comes from various sources: from inscribed stone monuments of the classic period, from hieroglyphic codices of the postclassic period, from Spanish chronicles and native ethnohistorical manuscripts of the postconquest period, and from modern ethnography. The primary sources, however, are the stone monuments and the presumably twelfth-century Codex Dresdensis (named for the library which has had it since 1739). Other sources either furnished the keys for the initial unlocking of the content of the primary sources or have offered supplementary

and comparative evidence for the interpretation of that content.[1]

The Maya left no treatises on mathematical or astronomical methods or theories. There is no posing of a problem, proof of a theorem, or statement of an algorithm—none of the usual kinds of source material for the history of a science. Their writing system, if not actually prohibitive of such disquisitions, was at least conducive to brevity in the extreme. What they left are the various end products of the application of their methods. It is up to the students of these remains to decipher what the problems were and what may have been the methods employed in their solution. This essay therefore, in some of its parts, must take the form of an analysis of the remains, and an argument, with the aim of deducing from them what knowledge of facts and of methods may have lain behind them. It can hardly take the form of a history of Maya mathematics, calendrics, and astronomy. Although the names of the rulers of the Classic Maya principalities are known, or at least the hieroglyphic forms of their names, the contributors to the Maya "sciences" remain totally anonymous. That is not to say, however, that some of the developments in this domain cannot be placed at least approximately in a historical time scale.

By way of an introduction to the content of the remaining pages of this essay, the following brief summary is presented.

1. Maya numeration was vigesimal. (It still is.) In the enumeration of days it was modified to accommodate a 360-day "chronological year."

2. Chronology was by means of a continuous day count, reckoned from a hypothetic zero day some three millennia B.C. (Precise correlation of the Maya with the Julian day count remains uncertain.)

3. Basic calendrical cycles were the "trecena" of 13 days, the "veintena" of 20 days, the "sacred almanac" of 260 days (the product of the trecena and the veintena), the "calendar year" of 365 days, and the "calendar round" of 52 calendar years or 18,980 days (the lowest common multiple of the sacred almanac and the calendar year). Others were of 9 days, 819 days, and 4×819.

4. A concurrent lunar calendar characterized days according to current moon-age, moon-number in lunar half-years, and moon duration of 29 or 30 days.

5. The principal lunar cycle, for warning of solar eclipse possibilities, was of 405 lunations (11,960 days = 46 almanacs), in three divisions of 135 lunations each, with further subdivisions into nine series of 6-month and 5-month eclipse half-years. The saros was a station in this cycle (the end of the fifth series) but was not recognized as the basic cycle.

6. Venus cycles were the mean synodic Venus year of 584 days, an intermediate cycle of 2,920 days (the lowest common multiple of the calendar year and the Venus year, equal to 8 of the former and 5 of the latter), and a "great cycle" of 37,960 days (the lowest common multiple of the sacred almanac, the calendar year, and the Venus year, equal to 104 calendar years or 2 calendar rounds). Reckonings with the periods of other planets are more difficult to establish.

7. The calendar year was allowed to drift through the tropical year, the complete circuit requiring 29 calendar rounds (1,508 calendar years, 1,507 tropical years). Corrective devices were applied in using the Venus and the eclipse calendars, to compensate for long-term accumulations of error owing to small discrepancies between canonical and true mean values of the respective periods. For numerology, canonical values were accepted at face value.

II. NUMERATION AND NOTATION

The history, or prehistory, of mathematics can be said to begin with the discrimination of *one*, *two*, and *many*, and with the naming of these concepts. Although admitted as true in a sense, it may hardly seem worth the saying; for we assume that people in all societies must enumerate things and that all languages must have number vocabularies capable of reaching at least into the hundreds and thousands. But when one has encountered a human language lacking this capability, one no longer takes numbers for granted. Such languages do exist; and the counting and computation done by speakers of those languages—whether as effect or as cause—is correspondingly limited. The Mayan languages are not among them, however. The names of the Maya numerical units up to 20^6 (or 64,000,000) are known, and in the enumeration of days, written numerals with higher-order units up to 360×20^{12} are recorded in inscriptions. The Maya probably had the highest development of numeration in indigenous America. But since it is exceptional, it is appropriate to view it as such, and to see it against the background of the mathematical resources of certain other aboriginal societies of the western hemisphere—for which purpose we shall make a brief detour into some comparative data. If the Maya were at the top of the

scale in regard to the development of numerals, then near the bottom of that scale are various tribal groups along the tributaries of the Amazon and on the central plateau of Brazil. Frequently reported are numeral systems consisting of the expressions "one," "two," "two and one," "two and two," "two and two and one," and "many"; for example, that of the Cachuianã, a people speaking a language of the Carib family and dwelling along the Rio Cachorro (a tributary of the Trombetas, one of the northern tributaries of the Amazon): *tuinerô* (1), *ahsakô* (2), *ahsakô tuinerô* (3), *ahsakô ahsakô* (4), *ahsakô ahsakô tuinerô* (5), *chicarauhô* ("many," "a lot"). A similar system has been reported by the Salesian Fathers Colbacchini, Venturelli, and Albisetti, and by General Rondon, from the Bororo Indians along the Araguaia and the São Lourenço in the uplands of Mato Grosso. In Rondon's version, with minor substitutions in orthography, it is as follows: *mito* (1), *pobe* (2), *augere pobe ma awo metuya bokware* (3), *augere pobe augere pobe* (4), *augere pobe augere pobe awo metuya bokware* (5), *augere pobe augere pobe augere pobe* (6), and so forth, up to 2 + 2 + 2 + 2 + 2 (10), but noting also an alternative expression for five, *awo kera upodure* ("this my hand all together"). Colbacchini and Albisetti reported the same or similar expressions, with the remark that ordinarily they simply show the fingers of the hand, or of the two hands, saying *inno* or *ainna* ("thus") or *ainó-tuǰé* ("only this many"). They also noted that to indicate five they show the left hand open, saying *ikera aubodure* ("my hand complete"), that for ten they show both hands saying *ikera pudugidu* ("my hands together"), and that going beyond ten they employ the toes of one foot, and beyond fifteen the toes of the other foot; and that when the objects counted are more than a number that they can express easily, they say *makaguraga* ("many") or *makaaguraga* ("very many"). In the summer of 1950 the present writer made a brief visit to the Bororo village of Pobore on the Rio Vermelho and was able to coax one man (one of the few who had enough knowledge of Portuguese for the undertaking) as far as "thirty" in the elicitation of numerals. Following is a sample of the results: (1) *ure mitótuǰe* ("only one"); (2) *ure póbe* ("two of them," or perhaps better, "a pair of them"); (3) *ure póbe ma ǰéw metúya bokwáre* ("a pair of them and that one whose partner is lacking"); (4) *ure póbe púibìǰi* ("pairs of them together, in reciprocity, or in sequence"); (5) *ure ikéra aobodúre* ("as many of them as my hand complete"); (6) *botúre ikéra aobowúto* (precise significance uncertain, apparently something about changing to the other hand); (7) *ikéra metúya pogédu* ("my hand and another with a partner"); (8) *ikerakó boeyadadáw* ("my middle finger," that is, of the second hand); (9) *ikerakó boeyadadáw mekíw* ("the one to the side of my middle finger," again omitting to specify that it is of the second hand); (10) *ikerakó boeǰéke* ("my fingers all together in front"; . . . (13) *ičare butúre ivúre boeyadadawúto pugéǰe* ("now the one on my foot that is in the middle again"); . . . (15) *ičare ivúre iyádo* ("now my foot is finished"); . . . (20) *avúre ičare maka réma avúre* ("your feet, now it is as many as there are with your feet"); (21) *otúre turegodáǰe pugéǰe* ("starting them over again"); (22) *ure póbe turegodáǰe pugéǰe* ("two of them, starting over again"). These were given as if they were names for numerals, without accompanying gestures of finger showing or pointing to toes.

The Bororo case has been cited because it shows vividly the basis for vigesimal systems (it is clear what counters are employed and named in the tally). It also enables one to appreciate the nature and length of the path that lies between a primitive one like the Bororo, with its long descriptive phrases, and an advanced one like the Mayan, with its brief unanalyzable roots for the numerals up to "ten," "eleven," or "twelve," rather than only up to "two" as in Bororo. A long history of ellipses, of accumulation of phonetic changes with resulting loss of etymological transparency, and of repeated abbreviations accompanying increased frequency of use, must lie between these two stages in the development of a number vocabulary.

An intermediate stage can be glimpsed in the numerals of the Iroquois Indians of the region of New York State, lower Ontario, and southern Quebec. These numerals are conveniently short words (in a language of the polysynthetic variety which is otherwise given to long and morphologically complex words), their etymologies do not intrude into the thoughts of the speakers who use them (only linguists notice their apparent origins), and they serve as excellently as do the numerals of any language in all of those uses to which spoken number words are put. But the etymologies of at least seven of the first ten numerals show through and reveal their original significations. Enumerations in amounts of "one" and "two," whenever the underlying stem will permit of it, are accomplished by inflection of the stem with appropriate prefixes and suffixes. The suffixes, however, are only apparently such; formally they are stative verb roots which incorporate the noun stems. The

independent words for "one" and "two" are composed of such inflectional elements, but without an incorporated noun stem; formally they are petrified stative verb forms. They are used only with expressions whose morphology will not accept the affixes. The word for "three" is homonymous with the verb root meaning "(to be) in the middle of it." The word for "four," in its unabbreviated form, is homonymous with the inflected word meaning "it is complete," probably owing its origin to a widespread ritual significance attached to the number four in Amerindian cultures. The word for "five" is unanalyzable in Iroquoian, but there is a word for "hand" which is of this form (and related forms) in some of the Caddoan languages, these being a very distantly related family. The word for "six" is homonymous with the bare verb stem for "to cross over," in the form which it has when no incorporated object noun stem is present. An original reference to crossing from one hand to the other seems to be implied. The words for "seven," "eight," and "nine" are opaque and at best are only weakly suggestive of possible origins. Two of the words for "ten" are transparent, or relatively so, while another is not. One of them is derived from a participial inflection of the same verb root as is contained in the word for "four" and must owe its origin to the fact that with "ten" a tally on the fingers is "completed." The Iroquois system is decimal.[2]

The Mayan numerals, in contrast to these, are opaque through "eleven" or "twelve." It is perhaps possible, although not proven, that words for "ten" may be derived from a root meaning "end" and "to finish" or "complete." Whether or not this is historically correct, there is nonetheless a decimal stratum within the otherwise vigesimal system of numeration, as can be seen in thirteen through nineteen of the following set from Yucatec Maya:

1. hun	11. buluc
2. caa, ca, c-	12. lahca
3. ox	13. oxlahun
4. can	14. canlahun
5. hoo, ho	15. hoolahun, hoolhun
6. uac	16. uaclahun
7. uuc	17. uuclahun
8. uaxac	18. uaxaclahun
9. bolon	19. bolonlahun
10. lahun	20. hun kal

[NOTE: Following tradition, the colonial Yucatec orthography is used in citations of words from that language. The letter *x* is for *š*; prevocalic *u* is for *w*; *c* is for *k*, regardless of whether it is before a back vowel or a front vowel; the letter *k* is for the midvelar glottalized stop *k'*. Thus *kal* in the above list is for *k'al*. The same word in highland Guatemalan languages, with the same initial consonant, was written *4al* in colonial orthographies and is mostly *c'al* in modern orthographies in that country, where the letter *k* is used to represent the postvelar stop in the indigenous languages, corresponding to *q* of standard international phonetic transcriptions. The glottalized postvelar was written *ƙ*. In Yucatec the Mayan postvelars were anciently merged with the midvelars. Doubled vowels in Yucatec orthography (except with syllable-initial *u* for *w*) are for vowels interrupted or checked by a glottal stop. Use of the convention, however, was inconsistent in Spanish colonial sources.]

Words for twenty, or score, in the Mayan languages are *kal* (*c'al*, and so forth; see above), *may*, and *uinic*, or forms cognate to one or another of these. The last of these is the word for "man" or "human being," implying in this context a reference to the totality of his digits. The others appear to be related to words for tying and bundling and may reflect practices of counting and packaging in ancient commerce and rendering of tribute.

Multiples of twenty in Yucatec are *hun kal* (20), *caa kal* (40), and so forth, up to *buluclahun kal* (380), after which is *bak* (400). Highland Mayan languages have *q'o* or *oq'ob* as the equivalent of *bak*. Some of the languages have separate words for certain of the intermediate multiples of twenty, such as *tu:c* (40), *much'* (80), and *lah* (200). Thus in Kekchi 200 is expressed alternatively as *laheb c'a:l* ("ten score"), *ho tu:c* ("five forties"), or *hun lah* ("one 200"); and 400 is *laheb tu:c* ("ten forties"), *ca'ib lah* ("two 200s"), or *hun oq'ob* ("one 400"), and in Cakchiquel, also *woo' much'* ("five eighties").

The powers of twenty, as far as their names are known in Yucatec, are *kal* (20), *bak* (20^2), *pic* (20^3), *calab* (20^4), *kinchil* (20^5), and *alau* (20^6). The Cakchiquel equivalent of Yucatec *pic* (8,000) is *chuwi*, which is also a word for "sack." Its use as a numeral is said to derive from the custom of packing cacao beans—an important commodity and also a medium of exchange—in quantities of 8,000 to the bag. Multiples of the higher powers of twenty are enumerated in the same way as are those of the first power.

There are two different methods of naming numbers that intervene between the multiples of any power of twenty. In Yucatec as it was spoken at the time of the Spanish conquest, and as it contin-

ued until about the end of the nineteenth century, the predominant method was to name the intervening quantity and to place it in the ordinal-numbered score or other power of twenty. Thus, for example, forty-one was "one in the third score" (*hun tu yox kal*), and 379 was "nineteen in the nineteenth score" (*bolonlahun tu bolonlahun kal*). This sytem still prevails today in most, although not all, of the Mayan languages. Ordinal numerals are formed by preposing the third-person possessive pronoun to the cardinal number. The preposition contracts with the pronoun; *tu* in the above examples is such a contraction. By analogy with these examples, for 399 one might expect "nineteen in the twentieth score"; but "twenty score" was regularly replaced by "one 400," so that 399 was expressed as "nineteen in the first 400" (*bolonlahun tu hun bak*), an expression that would be wholly misunderstood if interpreted either literally or in accord with the elliptical patterns about to be mentioned. For proper interpretation, *u hun bak* must first be understood as if *u kal kal*, that is, "twentieth score" rather than "first 400." This was the case only with the first multiple of *bak*, not with higher multiples. Thus, "nineteen in the third 400" (*bolonlahun tu yox bak*) was not to be understood as "nineteen in the sixtieth score," that is, 1,199. Neither, however, was it to be taken literally, in which case it would have had the value 819. Rather, its value was 1,180, for a reason that follows.

There were several curious but systematic ellipses. Between higher powers of twenty, simple numerals stood for multiples of the next lower power rather than for multiples of unity as if taken literally. Thus, for example, "five in the third 400" (*ho tu yox bak*) stood for "five SCORE in the third 400" (as if it were *ho kal tu yox bak*). This is the reason for the seemingly odd value given to the last example in the paragraph above. Another systematic ellipsis involved the word for two in references to the second score, the second 400, and so forth. The word was omitted (except in cases that called for yet a third and complementary type of ellipsis). Thus, whereas forty-five was "five in the third score" (*ho tu yox kal*), twenty-five was simply "five in its score" (*ho tu kal*), with the word for two suppressed. Similarly, whereas nine hundred was "five in the third 400" (*ho tu yox bak*), meaning "five SCORE in the third 400," five hundred was simply "five in its 400" (*ho tu bak*), meaning "five SCORE in the SECOND 400." This last expression is doubly elliptic. The third type of ellipsis (in a scale from the seemingly well-motivated to the seemingly whimsical) involved the syllable *tu*, which is the contraction of the preposition *ti* and the ordinal-forming pronoun *u*. It was something less than obligatory but was at least usual, if not wholly regular, in the particular context that permitted it. That context was a preceding word for ten (*lahun*) or for fifteen (*hoolahun* or *hoolhun*). It was not just a matter of the presence of the morpheme for ten, because none of the other teens precipitated this ellipsis. Nor was it a matter of multiples of five, because the first multiple of five also did not precipitate it. Thus thirty was "ten two score" (*lahun ca kal*), meaning "ten IN ITS two (that is, in the second) score." Similarly, six hundred was "ten two 400" (*lahun ca bak*), meaning "ten SCORE IN ITS two (that is, in the second) 400." This last expression also is doubly elliptic, although in a partially different manner from the expression for five hundred (*ho tu bak*). The last two types of ellipsis were complementary: a single expression could not combine both; but either of them could be combined with an ellipsis of the first type.

The second method of expressing compound numerals was to do it as we do: with a conjunction, either expressed (*catac* in Yucatec) or implied by juxtaposition of two orders of components, and proceeding from the higher-order to the lower-order components. Thus, for example, fifty-one could be either "two score and eleven" (*ca kal catac buluc*) or "eleven in the third score" (*buluc tu yox kal*) in the manner described above. Higher complex numerals could be expressed entirely in one of these ways, or entirely in the other, or by employing combinations of the two methods.[3]

In all of the preceding, attention has focused on numerals in spoken language. But for record keeping, and for computations other than the most simple, notational devices are required to give the numerals a permanence and retrievability lacking in the spoken word and in the unaided memory of the word. Iconic notation of low-order numerals is a ready adaptation of the tally or of the finger count, and this, together with symbols for extending the device to higher-order units, is one of the first systematic components of a primitive writing system. Thus, for example, in the Aztec system, numerals from one through nineteen were represented by aggregations of dots (in linear, broken-linear, or L-shaped array, and with various subgroupings, not necessarily by fives); scores were represented by flags, four-hundreds by treelike figures, and eight-thousands by ceremonial pouches such as shown being carried by divinities and by priests for the containment of copal incense.

The Maya notation employed dots for units up to four, bars for fives up to fifteen, and combinations of bars and dots for the intervening numbers. Thus the system of written numerals, unlike that of the spoken numerals, was quinary below and between the vigesimal values. Twenties were represented by the unit symbols positioned in second place (the base position, above or preceding the units position) in a system of place notation. Similarly, four-hundreds, eight-thousands, and so forth, were represented by the same symbols in higher-order places. (The apparent exception in the enumeration of days is only superficially such; see "Calendar, Chronology, and Computation," below.) Place notation requires a zero symbol for otherwise unoccupied places, and for this purpose a "shell" sign and several other hieroglyphs were employed.

There were also other symbols for twenty. By itself or in numerals up to thirty-nine, in contexts where place notation was not employed, that number was represented by the hieroglyphic sign that in other contexts refers to the moon or to the lunar month (a circumstance to be explained in the section "Calendar, Chronology, and Computation"). It is quite certain that the sign had different readings in these two functions; in Yucatec it would have been *kal* when interpreted as "twenty," and *u* (and perhaps sometimes *uen*) when interpreted as "moon" or as "lunar month." There were in turn two different methods of employing this sign in the value "twenty, which reflect the two different methods of expressing such numbers in the spoken language. In that which is most frequently attested, the sign for twenty is placed first and is followed by the numeral representing the excess over twenty. This, like the place numeration, reflects the conjunctive or "*catac*" method of expression in the spoken numerals. The other manner, attested only three times, reflects the more colloquial expression, including its idiomatic ellipsis; e.g., "nine in the SECOND score" (*bolon tu kal*), "sixteen in the SECOND score" (*uaclahun tu kal*), and so on. In these, the hieroglyphic sign having the phonetic value *tu* is prefixed to the *kal* sign.

III. CALENDAR, CHRONOLOGY, AND COMPUTATION

The system of numerical notation was at least seven or eight centuries old by the beginning of the "classic" period, late third century A.D. It is probable that the Maya received it ready-made, along with their chronological system and some of the components of their calendar, from other peoples in Oaxaca, Tabasco, and Vera Cruz. No doubt from its inception it was used—as it was when first observed by Europeans—in records of trade, levies of tribute, mensuration, census, and other functions of government and religion. Of special importance among the latter were chronology and the regulation of the calendar. It is almost exclusively in these that records of its use have survived for modern study. Although documents exhibiting other uses have survived from the Aztec and other peoples to the west, for example, listings of items of trade and tribute (from late postclassic and post-conquest times), none such has survived from the Maya. There are several instances, however, of enumeration of objects for offerings: nodules of copal, rolls of rubber, beans of cacao, "precious things" (whatever they were), and others yet undeciphered. Presumably then, as today, the numbers of things offered were as important as their kinds; for numbers had esoteric meanings and efficient powers in their own right. Particular combinations of numbers and kinds were prescribed—suited to the occasion, the recipient, or the day in the calendar. But outside of these, the only records of Maya numerical notation that we have are in its calendrical and chronological applications.[4]

The basic calendar of the Maya, as of other Mesoamerican peoples, was the 260-day almanac. It was the product of two component cycles: one of day numbers, from "one" to "thirteen," and one of day names, twenty in all. Any day in the compound cycle of 260 can thus be specified by a pair of coordinates: for example, *1 Imix, 2 Ik*, and so forth, to *13 Ahau*; or translated into numerical equivalents: (1, 1), (2, 2), · · · , (13, 20), expressing the position of the day in two simultaneous cycles of different moduli. The Maya name for the almanac is not known for certain; but in Mayanist literature it is commonly called the *tzolkin* ("the sequence of days," "the naming-in-order of the days"), on the grounds that it is an apt term, that an analogous one is documented for the sequence of calendar months (*u tzol uinal*—a syntactic phrase rather than a compound noun), and that even if this is not what it was actually called, the Maya could well have understood the term in that sense. In the present account, the term "almanac," or "sacred almanac," will be used. The component lesser cycles will be called the "trecena" and the "veintena," employing convenient Spanish terms. The names of the days of the veintena, in Yucatec (in a conventional but inadequate transcription), are *Imix* (1), *Ik* (2), *Akbal* (3), *Kan* (4), *Chicchan*

(5), *Cimi* (6), *Manik* (7), *Lamat* (8), *Muluc* (9), *Oc* (10), *Chuen* (11), *Eb* (12), *Ben* (13), *Ix* (14), *Men* (15), *Cib* (16), *Caban* (17), *Etznab* (18), *Cauac* (19), and *Ahau* (20). They have other names in other Mayan languages, some cognate and others not; but the hieroglyphs were the same, including variants, throughout the territory in which they were used, regardless of the local language. In non-Mayan language areas of Mesoamerica, not only the names, but also the hieroglyphs, were different.

The 365-day year was the other principal component in the calendar. Its name in Yucatec was *haab*, with cognate forms in other Mayan languages. The apparent derivation of the term implies a reference to the seasonal year (the "rains" being for the count of years in the tropics what "winters" have been in the temperate zones); but there is evidence for its nonspecificity of use, being interchangeable even with the word for the 360-day chronological year, with a corresponding interchangeability of the hieroglyphs, but with context serving to clarify the reference. In Mayanist literature the uncorrected 365-day year is commonly called the "vague year," or sometimes the "*haab*." Here it will be called the "calendar year," or simply the "year" (when the reference is clear from context). Any other kind of year—such as the "tropical year" of 365.2422 days, the "chronological year" of 360 days, or the "computing year" of 364 days—will be specially designated as such.

The calendar year was divided into eighteen named "months" of twenty days each, and a residual period of five days; and within each of these the constituent days were numbered or otherwise specified as to position. The numbers employed for days in the months were 1 to 19, and 1 to 4 in the residual period. In place of 20 in the months, and in place of 5 in the residue, the last day of any period was sometimes designated with a glyph whose reading was *tun*, a word with several senses (homonymous), one of which was "end" or "final." But far more frequently it was designated as the "seating" or "installation" day of the next month, employing a glyph of that meaning (also employed for the seating or installation of rulers) whose reading is assumed to have been *cul*, but for which there are also other possibilities. Thus, for example, the twentieth day of the month *Mol* was designated either as "end of *Mol*" or as "seating of *Chen*," the latter method being predominant. In transcriptions of glyphic texts, the seating day of a month is conventionally numbered "0," with the name of the month seated, since it is in effect the zero day of the month about to begin.

The term "month" is customarily employed for these periods in spite of the incongruity between the name and their duration. The reasons are (1) that some of the Maya are known to have done the same, and (2) that the hieroglyph for "twenty" is the "moon" sign. In regard to the first point, it has been reported in an early twentieth-century ethnographic study that specialists in the calendar among the Jacaltec Maya used the same word for the twenty-day month as did laymen in the community for the thirty-day period, which is also their word for "moon."[5] In regard to the second point, the glyphic usage is reasonably although speculatively explained on the assumption that a similar polysemy existed in ancient times also, with ultimate derivation of the special sense from the more general sense (possibly with the institution of an arithmetically motivated calendar, supplanting a lunar one in the function of subdividing the vague seasonal year). The Yucatec Maya names of the months are *Pop* (1), *Uo* (2), *Zip* (3), *Zotz* (4), *Tzec* (5), *Xul* (6), *Yaxkin* (7), *Mol* (8), *Chen* (9), *Yax* (10), *Zac* (11), *Ceh* (12), *Mac* (13), *Kankin* (14), *Muan* (15), *Pax* (16), *Kayab* (17), *Cumhu* (18); and the residue, *Uayeb*.[6] The names of the months are highly variable from one Mayan language to another; yet the hieroglyphs are universal, including variants, in the area in which hieroglyphic inscriptions are found. In about half of the cases, the forms of the hieroglyphs are explainable only by reference to non-Yucatec names for the months, particularly those of Kekchi, Pokom, and Jacaltec. The Yucatec readings, however, are standard in transcriptions of glyphic texts.

The days, named for their places in the calendar year—*1 Pop*, *2 Pop*, and so forth, through all of the months, to the end of the *Uayeb* (or "seating of *Pop*")—constituted the third principal cycle in the calendar. Compounded with the trecena and veintena of the almanac, it yielded a greater cycle, the "calendar round." Because 260 and 365 share a common factor of 5, the length of the calendar round is 52 calendar years, or 73 almanacs, or 18,980 days. A day in the calendar round was specified by its positions in the component cycles; for example, *12 Lamat 1 Muan*, which may be translated into numerical coordinates as (12, 8, 281), or vigesimally (12, 8, 14.1), representing a triple classification of the day according to its places in three cyclical schemes with moduli 13, 20, and 365 (18.5) respectively. Also because of the common factor of 5 in the veintena and in the calendar year and its subdivisions, any day in the veintena was restricted as to the positions it could

occupy in a month of the year, or in the *Uayeb*. Thus, the 5th, 10th, 15th, and 20th days of the veintena (*Chicchan*, *Oc*, *Men*, and *Ahau*) could fall on any of the days *3*, *8*, *13*, or *18* of a month, and on day *3* of the *Uayeb* period; with the others falling in place accordingly. And because the days of the year were eighteen score *and five*, the positions of the year days shifted five places in the veintena from one year to the next. Similarly, because they were one more than a multiple of thirteen, each year they fell one place later in the trecena.

The calendar round, with its three component cycles, provided a unique characterization for every day in a 52-year span of time. It was the most heavily employed system for the dating of events. Employed as it was with an occasional anchor to the day count, its specifications became unique in their reference, not just within a 52-year span, but for all time.

The Maya "day count" was the ultimate resort for absolute chronology. It was, like the Scaliger or "Julian" day count, a method of assigning a distinct number to each and every day in sequence, conceivably forever, or at least for the duration of an era, starting from a conventional zero point in time. That zero point for the Maya count—the theoretical start of their current chronological and cosmological era—was a day some three millennia before the beginning of the Christian era. Other eras, however, had preceded this one, and some dates (of mythological events or retrospective astronomical projections) were given in the chronology of the last preceding era. The duration of that one was treated as having been of thirteen *baktuns* (about 51¼ centuries). The zero day of the current era was thus also the final day of the preceding era, and was designated as the "end of thirteen *baktuns*," or 13.0.0.0.0 in the day count of that era. Its place in the calendar round was *4 Ahau 8 Cumhu*, or in numerical translation (4, 20, 348), or with the year day expressed vigesimally and the veintena day by its modular equivalent (4, 0, 17.8). There is no evidence as to whether a similar duration was envisioned for the current era (if it was, its end will soon be upon us) or for other preceding eras. In other words, grounds are lacking that would warrant our considering the day count also as cyclical.

Fundamental to the day count is the "chronological year" of 360 days. The hieroglyph designating this period is known from several kinds of evidence to have been read *tun*, and this was the Maya term for the chronological year. The glyph is the same as that used for the homonymous *tun* meaning "end" or "final," used at times for the designation of the last day of a calendar month. The chronological years, or *tuns*, were counted vigesimally. The next higher unit was the *katun*, equal to twenty chronological years. The name for the unit is well attested from postconquest documentary sources; it is quite surely from *kal* ("twenty" or "score") plus *tun*, with loss of syllable-final *l* (under phonological conditions in which such loss has ample precedent). The unit beyond the *katun* was that of 400 chronological years, presumably called the *baktun*, although the term is unattested in postconquest sources, and its hieroglyph does not in itself compel that reading. In Maya historical chronology no further higher-order units are needed; but in the numbers employed for long-distance projections into the future and into the past, hieroglyphs are found whose values, by powers of 20, range up to 64 million chronological years or *tuns*. It is supposed that the names for these units were most likely compounded from the corresponding numerals and the word *tun*, and on this assumption they are commonly called the "*pictun*," "*calabtun*," "*kinchiltun*," and "*alautun*"; but these compounds are not attested in postconquest sources, although their constituent morphemes are.

The count was not just one of chronological years, but of days. Units of order lower than the *tun* were the *uinal*, amounting to twenty days, and the *kin*, single days. In its adaptation to the count of days, the numerical system was thus vigesimal in all of its places but one, namely in the third. That is, every higher-order unit is equal to twenty units of the next lower order, except the third; that one, the *tun*, is equal to eighteen of the next lower order—a detail that must not be forgotten when doing additions and subtractions or other arithmetic manipulations with Maya chronological numerals. Although *kal* is the general term in Yucatec Maya for aggregates of twenty, and was employed in some contexts also for spans of twenty days, in the day count the term *uinal* and its particular glyph were employed. The term is documented in postconquest sources both in this sense, that is, of twenty-day units in counting, and also in the special sense of the twenty-day named months of the calendar year.

In Mayanist literature the count of days from *4 Ahau 8 Cumhu*, 13.0.0.0.0, is commonly called the "long count" (abbreviated LC), although some have extended that term also to long reckonings from special bases antedating the normal zero, and have extended the term "initial series" (abbreviated IS, see below) to designate such reckonings as are

made from the *4 Ahau 8 Cumhu* zero date and are placed at least in the almanac, whether they are "initial" to any text or not. Here it will be called the "day count," or "Maya day count" when a contrast with the Julian is required. A date is fixed by its "day number."

In hieroglyphic inscriptions on stone monuments, dates spelled out in full in the day count were usually confined to the initial passage of a text and were given the most artful elaboration and prominent display in the inscription. The initial passage opens with a standard "introducing glyph," often double or quadruple the size of the other glyphs, which may have had a conventional reading. Infixed into it is a variable element, varying according to the calendar month which appears further on in the elaboration of the date, and was thus in some way symbolic of that month (patron deity?, hieroglyph of an ancient name?). Following the introducing glyph, the numbers of *baktuns, katuns, tuns, uinals*, and *kins* that constitute the day number are given, sometimes simply with bars and dots prefixed to standard forms of the signs for the unit periods, but often with ornate personified forms symbolic of the numerals, and zoomorphic forms for the periods, these being portrayed either as heads or more elaborately as full figures. Following this numerical specification of the place of the date in the day count there are given its positions also in the almanac and in the calendar-year, as well as in other supplementary cycles. One of these is a cycle of nine days, the position in this being given by naming the one of the nine lords of the night under whose regency the given date falls. Another is the lunar calendar, the position in this being specified by giving the age of the current moon on this date, the numerical position of the moon in its lunar half-year, and the prescribed duration of this lunar month (or the preceding?) whether of 29 or of 30 days in the lunar calendar. Placement in these cycles—almanac, calendar year, lords of the night, and lunar calendar—was standard procedure for the initial date of a major inscription, in addition to its placement in the day count. There was yet another cycle, of 819 days and somehow involving the rain god, which attained importance at some sites, and in which the date might also be placed by specifying how many days it was past the last station (or zero day) in that cycle; and since the stations rotated with the cardinal directions and colors, which also were specified, this became in effect a 4×819 or 3,276-day cycle. The order of all of these characterizations of a date was fixed, as just enumerated, except for some variability as to where placement in the calendar year was inserted. Sometimes, although relatively infrequently, this followed immediately after the placement in the almanac. Sometimes, but even less frequently, it came just after the phrase pertaining to the lord of the night. Most frequently it followed the lunar data; and in at least one inscription it followed the placement in the 819-day cycle.

In the alphabetic code designations employed in Mayanist literature—a code imposed before the meanings of the glyphs were known—the so-called "supplementary series" of glyphs is as follows, and in this order: (*G*) the place in the nine-day cycle, presumed lord of the night; (*F*) a constant glyph that follows glyph *G*, or into which glyph *G* is infixed, which perhaps names the standard event of which the particular lord of *G* is protagonist—or the constant predicate of which the variable *G* is subject; (*E*) the excess over 20 days, if any, in the age of the current moon on the date specified; (*D*) the age of the moon up to and including 20 days, supplemented by the preceding glyph *E* when over 20 days; (*C*) the position of the month in the lunar half-year; (*X*) a variable glyph, in a cycle of the same magnitude as that of glyph *C*, and partially constrained by the value of *C*, the meaning of which is not known; (*B*) a constant glyph—except for apparently free alternation among supposedly equivalent signs in two of its component parts—whose meaning is not known; and (*A*) the calendrical duration of the moon in question, always 29 or 30 days. Placement of the date in the almanac precedes this series; placement in the calendar year may precede it, or may intervene (although but rarely) between *F* and *E* or *D*, or may follow *A* (its most usual position). Placement in the 819-day cycle, if present, is usually last.[7]

Only after such characterization of a date in all of its important aspects, which constitutes a compound temporal-adverbial phrase or clause in the sentence, only then are the event and its protagonist stated. The events are of a suitable importance: the births of gods, the births of rulers, and the rulers' observances with the proper religious rites of momentous turns in the day count. The initial date and its event furnish the anchor, both thematically and chronologically, for the events and dates enumerated in succeeding passages. These dates were usually given only in the calendar round, that is, by naming the pertinent almanac day and year day. The rest of the attributes of such a date, including its number in the day count, could be determined from its calendar-round position in

relation to that of the initial date. The information for anchoring these "secondary" dates in the chronology was sometimes made explicit in the form of "distance numbers" that linked the dates of successive passages to those of preceding ones. Sometimes, however, the function of distance numbers was to connect two dates of a pair in a single passage to each other, rather than to connect either of them with the date of a preceding passage. But their relation to a preceding date was clear nonetheless, it being understood that the indicated calendar-round day was the *next* such after the calendar-round day of the preceding passage, or after the later one of a linked pair in that passage, *unless otherwise specified.* And there were several ways of making it clear if that was not to be the case. Thus the day number corresponding to such a date could be supplied, provided only that one knew how to compute the interval between any two calendar-round days.

One of the ways of anchoring secondary dates was to insert into the sequence the calendar-round day corresponding to a round-numbered period-ending: for example, "*8 Ahau 13 Ceh*, completion of nine *baktuns*," meaning 9.0.0.0.0; or "the period-ending" of 5 *Ahau 3 Chen*, therefore 9.8.0.0.0, it being understood that "period-ending" meant "*katun*-ending" unless otherwise specified, in which case this date is the only possibility within 18,980 chronological years (18,720 calendar years); or "the period-ending of *5 Ahau 18 Tzec, oxlahuntun*," therefore 9.8.13.0.0, this being a case where the "otherwise" is specified. Such chronological anchors, employed when necessary or pertinent, could be linked by distance numbers to other dates in a concatenation; or in unconcatenated texts they could be paired with other dates when necessary to remove potential ambiguities. Or in sequences without distance numbers, they could be inserted as chronological guideposts. In one known case the number of *katun*-endings intervening between two dates is given, thus assuring that the later one is not the next but the second-next occurrence of that calendar-round day. It is apparent that care was taken to eliminate ambiguities in such sequences. There are remarkably few; and some dates once thought to be unanchorable turn out only to be anchored by means then undetected.

The texts accompanying these secondary dates have rather limited and stereotyped subject matter: births, heir designations, and accessions of rulers; in some cases also marriage and the seating of a wife as queen mother and nominal coruler; a few records of the taking of high-ranking captives; performances of rites for the gods; some records of deaths or interments of rulers; lines of lineal descent; mythological ancestry; events involving the gods in ancient times, possibly with astronomical or mythico-cosmological references; a single probable record of a historical eclipse and possibly one or two others; and other matters not yet understood.[8] The syntactic patterns are formulaic, in the majority of cases simple but in some quite complex; and some of the latter preserve a couplet structure—parallel statements of same or similar import, the second rephrasing or amplifying the first with different but synonymous or partially synonymous expressions. It is a pattern that appears in certain postconquest pieces of Mayan traditional literature (recorded by native writers in romanized alphabets) and of which some beautiful specimens have been encountered in the oral literature also of other Amerindian peoples, of both North and South America. The fact that a few applications of this structural formula made their way into some of the hieroglyphic texts, however, should not be construed so as to suppose that they might be read as poetry; but they do give a glimpse of the linguistic and poetic resources that must once have existed for Mayan oral literature, and of the kinds of oral forms that may have been associated with the glyphic texts as prior versions, expansions, or traditional commentaries on them.

In addition to the other technical and artistic skills that went into the compilation and execution of the hieroglyphically inscribed monuments, a considerable skill and labor must have gone into the calendrical work contained in them. There are occasional arithmetical errors: a few rare ones that display real incompetence and apparent bluffing, a few that suggest copying errors (although one wonders why preliminary sketches on stone were not proofread before carving), and others that reflect the all too human kinds of mistakes in arithmetic or in table consultation. But in proportion to the amount of computation that must lie behind the Maya inscriptions and codices, the frequency of error is indeed low. Certain kinds of problems were faced over and over again. There were, of course, simple additions and subtractions of numerals in the modified vigesimal system of the day count, involving "carrying" and "borrowing." Whether the steps in these were carried out mentally, or with the aid of counters of different varieties or in different places, or with scorings on the ground or on sand tables or on other flat surfaces, is a minor matter. They were done, and for the most part they were done accurately. It is doubtful

that the Maya did multiplications, other than by two and by twenty, except by repeated additions. There are no records of elementary multiplication tables, although in the codices there are tables of multiples of important longer periods (a few of which will be seen in following sections). Multiplication by twenty was relatively simple. Any day-count number that had a zero in second place (the *uinals* place) could be multiplied by twenty simply by adding a zero to the terminal end of the number. If the second-place number in the multiplicand was not zero, then the first step was to proceed as before and the second step was to double the second-place number of the multiplicand (now the third-place number in the intermediate product) and contribute it to the second place of the product. Of division there was surely less need in day-count arithmetic than in ordinary arithmetic, say as employed in commerce; but in ordinary arithmetic all processes were simpler because in that the base factor was uniform in all places of a number.

Beyond the elementary processes, as modified for day-count arithmetic, there were two important types of reckoning in applying the count to the calendar round. The two most typical problems were that of adding an increment (or decrement) to a given position in the calendar round, and that of determining the interval between any two given positions in the calendar round. We may pose these according to our fashion, not knowing what phrasings the Maya may have given to them. The first is the simpler one.

I. Proceeding from a given initial day (t_0, v_0, y_0) in the calendar round, what will be the day (t, v, y) reached in that round after the lapse of n_5 *baktuns*, n_4 *katuns*, n_3 *tuns*, n_2 *uinals*, and n_1 single days?

Our approach would be first to write three formulas in which the positions of the terminal day in the trecena (t), in the veintena (v), and in the calendar year (y) are expressed as functions respectively of t_0, v_0, and y_0, and the relevant n_i. For historical time in the day count, i ranges to 5; so for the time being we may restrict it to that maximum. The formulas may then take the following forms:

(1) $t = t_0 - n_5 - 2n_4 - 4n_3 + 7n_2 + n_1$, mod 13;
(2) $v = v_0 + n_1$, mod 20;
(3) $y = y_0 + 190n_5 - 100n_4 - 5n_3 + 20n_2 + n_1$, mod 365;

or with the last one in equivalent vigesimal form; where each coefficient in higher positions is derived from the next lower one (the one to its right) by multiplying it by the pertinent base factor (18 for n_3, 20 for all others) and reducing the result by the appropriate modulus (13 for t, 20 for v, and 365 or vigesimal 18.5 for y). In the case of the expression for v, all higher coefficients vanish because of the equal magnitudes of the first base factor and the modulus. The choice of a positive or a negative coefficient is obviously open in each case (for example, the expression for y could just as well be written as $y_0 - 175n + \cdots$, mod 365), such choices being made as will best facilitate mental calculation.

How did the Maya calendar priests do it? Direct evidence is lacking. It is possible to imagine all sorts of ways. But it is hard to imagine that there was not among them a method that was essentially equivalent to the one above—minus, of course, the algebraic format. First, it was an elementary matter to add single days (compare coefficients of unity for n_1). Second, it was surely common knowledge—as it is wherever the almanac survives today—that each successive recurrence of any day of the veintena had a place in the trecena that is seven places ahead of its previous one; thus, for example, the next *Ahau* after *1 Ahau* is *8 Ahau*, and so forth (compare coefficient of 7 with n_2 in the above expression for t). And it must have been equally well known that the second-next occurrence of any day of the veintena was just one place further along in the trecena; for example, that the second-next *Ahau* after *1 Ahau* is *2 Ahau*. These forty-day or two-uinal intervals have been remarked upon for this property by Jacaltec Maya, who call them *u yoc habil*, the "feet," or perhaps "footsteps," of the year, because they measure off one-day advances in the trecena associated with a constant place in the veintena.[9] Third, no one can have escaped knowing that every major chronological period ended on a day *Ahau*, and that these—the *tuns*, the *katuns*, and the *baktuns*—were named for their terminal almanac days, always *Ahau*, but varying their positions in the trecena. These names appear to have been as much common parlance as our numerical names for the years, decades, and centuries; so it is probable that the cycles of their positions in the trecena were well known. But if not, at least it was common knowledge for the specialists. The Paris Codex outlines the cycle of *tuns: 7 Ahau, 3 Ahau, 12 Ahau, 8 Ahau*, and so forth, always regressing four places in the trecena (compare the coefficient of −4 with n_3 in the above expression for t); and it does the same for the *katuns: 4 Ahau, 2 Ahau, 13 Ahau, 11 Ahau*, and so forth, always regressing two places (compare the coefficient of −2 with n_4 in the same formula). And circular arrangements of the *katuns* in postcon-

quest sources, the so-called "*katun* wheels," present the same information in another format well designed for rapid calculation.[10] Finally, the order of the *baktuns*, with regressions of just one place in the trecena (compare the coefficient of -1 with n_5 in the expression for t), was so simple as hardly to require a visual aid; although wheels, or linear arrays understood to repeat, could well have been employed to facilitate each step in a computation. Determination of the place attained in the trecena after the lapse of any amount of time, whether a few days or thousands of years, could thus have been a fairly simple task. The place in the veintena was even easier to ascertain, since it depended only on the lowest-order digit in the distance number.

Reckoning of the place in the calendar year might have been done by analogous procedures, not different in principle, but more cumbersome and thus inviting the invention of other sorts of aids. For this we have even less evidence; we know that it was done, but we can only guess at the means. In any case, the combination of a vigesimal system of numeration and a vigesimally subdivided calendar year certainly facilitated the procedure. There would have been an advantage in reckoning *baktuns* in pairs, up to the last one if their number was odd. A tabulation such as the following makes the task quite simple:

Day-Count Increments	Calendar-Year Moves
2 *baktuns*	+ 15 days
1 *baktun*	+ 9 *uinals* + 10 days
1 *katun*	− 5 *uinals*
1 *tun*	− 5 days
1 *uinal*	+ 1 *uinal*
1 day	+ 1 day

A convenient visual aid would have been a simple list of the hieroglyphs of the eighteen 20-day months, together with the *Uayeb*, for tallying and place keeping. Crossing the *Uayeb*, of course, requires a five-day adjustment in the month day (subtraction if going forward over the *Uayeb*; addition if regressing in the sequence) and sometimes a concomitant change in the month.

Finding the calendar-round day corresponding to a date given in the day count is the same kind of problem. For this, *4 Ahau 8 Cumhu* is the initial day, and the Maya day number is the increment.[11]

This subject requires no further elaboration and can be left by posing a problem for the reader: *Determine the calendar-round day corresponding to the day number 9.9.2.4.8.* (The numerical equivalents of the veintena day names and of the month names have been given above.) The answer is *5 Lamat 1 Mol.* It was the accession day of the ruler known as Pacal, or Sun Shield, whose remains lie in the sarcophagus within the crypt under the Pyramid of the Temple of the Inscriptions at Palenque, in present-day Chiapas, Mexico.

Should this have given no difficulties, a second may be in order, which will require expansion of the above formulas (according to the stated rule) so as to accommodate a seven-place distance number: *Find the calendar-round day that is 7.18.2.9.2.12.1 after a day 1 Manik 10 Tzec.* The answer is the same: *5 Lamat 1 Mol.* In the inscription of this monument the date of accession of the ruler is related first to his birth date: "12.9.8 from the birth of SHIELD-Pacal on *8 Ahau 13 Pop* to the accession of 'Great-Sun' SHIELD-Pacal on *5 Lamat 1 Mol*" (he was then a boy of twelve, his mother having acted as regent until he was old enough to be named ruler). Then the accession date is anchored in the day count: ". . . which was 2.4.8. after the *3 Ahau 3 Zotz* period-ending" (that is, after, 9.9.0.0.0). And then it is related to the "enthronement" of a mythological ruler or ancient deity who is said to have ascended to power about one and a quarter million years earlier: "7.18.2.9.2.12.1 from the enthronement of XXX (name of deity) on *1 Manik 10 Tzec* to the enthronement of 'Great-Sun' SHIELD-Pacal of the Royal Line of Palenque."

The other major type of calendrical problem may be posed as follows:

II. Given any two days in the calendar round, (t_1, v_1, y_1) and (t_2, v_2, y_2) respectively, what is the magnitude of the interval from the first to the second? ("Interval" here is normally to be understood to mean "minimal interval," that is, less than the duration of one full calendar round; longer intervals with the same initial and final days may be derived from the minimal interval by adding to it appropriate integral multiples of the calendar round, 2.12.13.0, or 18,980 days.)

This was possibly the most frequent type of problem that the Maya calendar mathematicians had to solve; for dates were most recorded, and presumably most remembered and talked about, in terms of their calendar-round specifications. These must normally have been the "givens"; distance numbers and placements in the day count probably required computation in most cases. Again we have ample evidence that the Maya solved these problems successfully, but no direct evidence as to how they did it. Our natural approach, of course, is to derive such formulas as are necessary and use

them. We can only guess at theirs. Because of the constraints of the problem, however, we can anticipate that there must necessarily be some underlying formal equivalences between their methods and ours, however much these may be masked by differences in the phraseology and devices employed.

The solution to the problem requires first the separate determinations of the minimal intervals in each of the three component cycles, that is, in the trecena (Δt), in the veintena (Δv), and in the calendar year (Δy); then, from the first two of these, also the minimal interval in the almanac (Δa); then, from the almanac interval and the year interval, the number of whole calendar years (n_Y) that are contained in the calendar-round interval; and then, finally, from that integral number of years together with the fractional year interval, the number of days in the calendar-round interval (Δcr) is determined. The formulas may take the following forms:

(4) $\Delta t = t_2 - t_1$, mod 13. $\Delta v = v_2 - v_1$, mod 20.
$\Delta y = y_2 - y_1$, mod 365.
(5) $\Delta a = 40(\Delta t) - 39(\Delta v)$, mod 260.
(6) $n_Y = \Delta a - \Delta y$, mod 52.
(7) $\Delta cr = 365\ (n_Y) + \Delta y$.

The derivations of formulas (5) and (6), a trifle lengthy, need not be presented here. The others are mere expressions of definitions.

Again we should ask: How might the Maya have done it? Only the tasks corresponding to formulas (5) and (6) require consideration. Equation (5) may be rewritten as

(5*a*) $\Delta a = \Delta v + 40\,(\Delta t - \Delta v)$, mod 260,

which expresses the almanac interval as the sum of a different pair of two parts: the first consisting of a series of one-day steps that move the veintena day from its initial position to one that agrees with its final position; and a second consisting of a series of forty-day steps (*u yoc habil*!) that move the trecena day by an amount equal to the difference between its initial position and its final position, less the amount already accounted for by the moves it has made in accompanying the veintena day in its shift. It will be remembered that the special property of the forty-day "footsteps" was that they advanced their position in the trecena by one day per step while remaining stationary in the veintena. Since the Maya were clearly aware of this property, at least some of them having given the period a name that expressed the property, it is reasonable to assume that they may once have put it to some use; perhaps *this* use. If so, they would have reckoned almanac intervals more or less in the following fashion. Let us pose a particular problem: *What is the interval from 8 Ahau 13 Pop to 5 Lamat 1 Mol*? A Maya computer might have proceeded thus, tabulating his positions or counting them off with the aid of some device:

8 Ahau
9 Imix
10 Ik
11 Akbal
12 Kan
13 Chicchan
1 Cimi
2 Manik
3 Lamat — 4 Lamat — 5 Lamat.

Proceeding down the column at the left takes eight moves of one day each; and proceeding to the right in the last row takes two more moves amounting to forty days each. Therefore the interval within the almanac from *8 Ahau* to *5 Lamat* is 88 days, or in Maya notation 4.8, that is, four score and eight days.

Next we would wish the interval within the calendar year, from *13 Pop* to *1 Mol*. The latter is the first day of the eighth calendar month, numerically "one in the eighth score" (*hun tu uaxac kal*), or in the alternative manner of expression "seven score and one" (*uuc kal catac hun*), whence the notation 7.1. Similarly, the year day of the earlier date, *13 Pop*, is 0.13. Subtracting the earlier from the later, we find the interval between them, Δy, to be 6.8 or 128 days. The computation of intervals within the calendar year was the simplest sort of problem for the Maya, even when crossing the *Uayeb* was involved, or when application of the modulus 18.5 was required. (The task is more difficult for us in our calendar, with months of variable lengths and unrelated to our arithmetic base.)

For the next step numerous alternatives are open. Proceeding as we would, according to formulas (6) and (7), they would have found the number of whole years contained within the desired calendar-round interval to be (88 − 128) + 52, or 12 calendar years. Twelve of these are 12.3.0 in day-count notation. To this sum would be added the fractional year just determined above, which was 6.8, resulting in 12.9.8 as the calendar-round interval between *8 Ahau 13 Pop* and *5 Lamat 1 Mol*, that is, twelve chronological years (*tuns*) plus nine score and eight days.

It is not known whether this was the Maya way. It probably was not. It is more likely that one or two other methods were in use, and there is cir-

cumstantial evidence favoring one of them. At any rate, they must have been aware that the difference between what we have called Δa and Δy, the interval in the almanac and the interval in the year, is always divisible by five (if it is not, someone has made a mistake).

Consider that the probable procedure for reckoning intervals in the almanac was that sketched in the fourth preceding paragraph above, the strategy of which was to move toward the goal in the veintena by one-day steps and then, holding the veintena day constant, to move toward the goal in the trecena by forty-day steps. This precedent suggests analogous procedures for reckoning intervals also in the calendar round. For example, one may move toward the goal in the almanac by the method just mentioned, and then, holding the almanac day constant, move toward the goal in the calendar year by steps of some magnitude that is a multiple of the almanac and affords a convenient measure. Or alternatively, one may move first toward the goal in the calendar year by the simple arithmetic method shown above, and then, holding the year day constant, move toward the goal in the almanac by steps of some magnitude that is a multiple of the length of the calendar year. In either case, whether the minimal interval in the calendar round was desired, or an interval of some larger approximate magnitude (say greater than some known number of *katuns* or *baktuns*, or passing over some specified number of *katun*-endings), a table of multiples of the calendar round would have been a necessary adjunct to reduce or augment the result (sometimes negative) to the desired proportion. Although such a table (2.12.13.0; 5.5.8.0; 7.13.3.0; and so forth) has not survived — except for the preface to the Venus table, which has the even-numbered multiples as far as to eight calendar rounds, 1.1.1.14.0—tables of multiples of other intervals have survived in the codices. Therefore since the construction of such a table was well within Maya competence, and since the need existed, we may assume that the tables did also. (Mayanists have constructed them and use them constantly.)

From equations (6) and (7) the following facts are readily apparent:

A. If the year day and the veintena day are held constant and increments are applied to the trecena day, then each one-day increment in the trecena reflects a 40-year increment, or a 12-year decrement, in the calendar round.

B. If the almanac day is held constant (that is, in both the trecena and the veintena) and increments are applied to the year day (they can be applied only in multiples of five, because of the constraints mentioned earlier), then each five-day increment in the year reflects a 5×364-day decrement in the calendar round, and conversely, each five-day decrement in the year reflects a 5×364-day increment in the calendar round. Note that 5×364 is equal to 7×260, which is 5.1.0 in Maya numeration, or 1,820 days.

Other such facts, reflecting other manipulations of the variables in the specification of calendar-round days, can also be brought out; although for present purposes these will suffice. But in such manipulations it must be remembered that if the year day is held constant, the value of the veintena day cannot be altered except in amounts that are multiples of five; and that if the almanac day, or the veintena day by itself, is held constant, then the year day cannot be altered except by similar quinary amounts. The trecena day, however, can be varied freely in computation problems.

Two additional alternatives are thus open for the second step in our illustrative problem of determining the calendar-round interval between *8 Ahau 13 Pop* and *5 Lamat 1 Mol*. Having determined the interval between the almanac days, we may exploit *B* above; or having determined the interval between the year days, we may exploit *A*.

Reckoning by means of *A* would go as follows. From *8 Ahau 13 Pop*, which is on year day 0.13, to the next *1 Mol*, year day 7.1, is an interval of 6.8 (by subtraction of the former year day from the latter). But the next *1 Mol* would be calendar-round day *6 Lamat 1 Mol* (because an increment of 6.8 added to almanac day *8 Ahau* reaches almanac day *6 Lamat*; compare formulas [1] and [2]). Further, from *6 Lamat 1 Mol* to *5 Lamat 1 Mol* is an interval of 12 calendar years, or 12.3.0 in Maya day-count numeration (because there is a decrement of 1 in the trecena value while all else is constant, and according to *A* this must result from an increment of 12 years in the calendar round). Adding now to this the fractional part of a year as first determined, we have $12.3.0 + 6.8 = 12.9.8$.

Reckoning by means of *B* would go as follows. From *8 Ahau 13 Pop* to the next *5 Lamat* is an interval of 4.8 (as determined by the method for calculating intervals within the almanac; compare formulas [4] and [5]). But this next *5 Lamat* would be the calendar-round day *5 Lamat 1 Xul* (because an increment of 4.8 added to *13 Pop*, year day 0.13, reaches year day 5.1 or *1 Xul*). Further, from *5 Lamat 1 Xul* to *5 Lamat 1 Mol* is a decremental interval of 40×364 days, $(2.0) \times (1.0.4)$

in Maya day-count notations, or −2.0.8.0; which, modulo 2.12.13.0, is equivalent to an increment of 12.5.0 (because in this pair of calendar-round days the almanac portions are constant and the interval from year day *1 Xul* (5.1) to year day *1 Mol* (7.1) is 2.0 or 40 days, and because, according to *B*, this must result from a decrement in the amount of that number of 364-day intervals, or from the complementary increment). Adding now to this increment the fractional part of an almanac as first determined, we have 12.5.0 + 4.8 = 12.9.8.

There are thus three (that is, at least three) alternative procedures for determining intervals between calendar-round days, given the interval in the almanac and/or that in the year. Analogously there are three alternatives for determining intervals between almanac days, proceeding from the interval in the trecena and/or that in the veintena. Of these latter, only two have been described. The third is like the second, except that it moves first toward the goal in the trecena by one-day steps, and then toward the goal in the veintena by 39-day steps, each effecting a one-day regression in the veintena; instead of, as before, moving first toward the goal in the veintena by one-day steps, and then toward the goal in the trecena by 40-day steps, each effecting a one-day advancement in the trecena. The point to be made is that the two nonalgebraic methods for computing intervals in the almanac, and the two similar methods for computing intervals in the calendar round, employ a single uniform strategy for dealing with two-variable problems of a sort inherent in a calendrical system employing simultaneous cycles of differing lengths. It is a strategy whose discovery and execution are entirely compatible with the stage of mathematical development that had been attained by the Maya at the very beginning of the classic period, or by their precursors even earlier. One ventures to suppose that it may have been their method. Circumstantial evidence possibly supportive of this hypothesis are (*a*) the modern ethnographic relic of the recognition and naming of the 40-day steps that serve in one of the alternatives for reckoning almanac intervals; and (*b*) the preservation in the Dresden Codex of several tables of multiples of 5.1.0, that is, of 1,820 days, which is equal to 5 × 364, and to 7 × 260. The tables are subdivided in various ways, passing either through 364 or through 260 in their buildup to 1,820. Two of them reach 400 × 364, or Maya 1.0.4.8.0. Because of some of its other useful properties in relation to the almanac and the calendar year, the 364-day period has been called the "computing year." Its potential role in the computation of intervals within the calendar round is comparable to that of the 40-day "footsteps" in the computation of intervals within the almanac. One thing is certain: the Maya calendar specialists regularly had to make such calculations, and most of the time they did them correctly. Still needed, however, is a thorough analytical study of the errors that they made, both in the inscriptions and in the codices. Such a study, not yet done, might furnish further and more substantial evidence on the computational methods of the Maya.

It should be added that the problem of placing a calendar-round date in the day count is simply a special case of the problem just discussed. In this, the initial calendar-round position is *4 Ahau 8 Cumhu*, and the final one is whatever day it is that is to be placed in the day count. The minimal interval between the two positions is determined by one of the methods above. To this, then, is added whatever multiple of the calendar round will bring the date into the anticipated range in the day count, or will allow it to have a certain moon age, or will be compatible with any other piece of information or circumstantial evidence about some aspect of the date or of the personages named in the inscription. If the range or the constraints are poorly defined because of paucity of context, plausible alternatives may at least be enumerated. Usually, however, they can be fixed with fair certainty.

This discussion of computation problems has focused on the almanac, the year, the calendar round, and the day count. There are others, inasmuch as the complete specification of a date in the initial passage of a monument normally included also its position in the nine-day cycle of glyphs *G*, the lunar data, and at least optionally its place in the 819-day cycle. The first of these is easily determined from the lowest two places in the day number, once it is known that the one occurring with all *tun* endings (multiples of 360 in the day count) is conventionally called *G*9. Thus:

$$G = 2n_2 + n_1, \text{ mod } 9. \tag{8}$$

The numerical *G* values refer to hieroglyphs whose identities are well known but whose precise significations are not.

The place in the 819-day cycle requires, and probably required for the Maya, a table of multiples of 819, Maya 2.4.19, up to the twentieth, which is 2.5.9.0, and then higher multiples of 2.5.9.0. This last is one of the numbers that had numerological importance, being the lowest common multiple of the almanac and the 819-day peri-

od, as well as of the 364-day computing year. (Factored, it is $2^2 \cdot 3^2 \cdot 5 \cdot 7 \cdot 13$.) It was employed, for example, in fixing two important mythological dates at Palenque.

The position in the trecena of all 819-day stations was the same, since the number is divisible by 13. The trecena position was 1. All positions in the veintena were occupied, with one-day regressions in that cycle from one 819-day station to the next. Three days before the zero of the day count is a convenient station to use as a reference point in reckoning; although it is not known whether the Maya had a traditional zero point for their reckoning. The earliest one recorded was at a distance of 6.15.0 before the beginning of the current era. Directions and directional colors were assigned to the stations. Those on days 1, 5, 9, 13, and 17 of the veintena (*Imix, Chicchan, Muluc, Ben*, and *Caban*) were of the east. The others followed from these, the assignments being in agreement with the normal counterclockwise rotation when proceeding forward through the days of the veintena; but since successive 819-day stations regress in the veintena, the sequence here is clockwise. Colors associated with directions were red with east, white with north, black with west, and yellow with south.

In the lunar series there were three items of data: the age of the current moon, the place of the moon in the current lunar half-year, and the duration of the current moon (or the immediately past one?) in the lunar calendar. There were variations from site to site and from time to time in the evaluations of moon ages. One-day variations might be attributable to variability of conditions, both meteorological and topographic, affecting visibility of the new moon, but there are also other factors that may enter into this when the recorded ages are results of computations rather than of observation. Three-day variations must be attributed instead to different conventions regarding the zero point for the count of days or nights in the age of the moon; and occasional four-day variations may be attributed to combinations of factors. It is concluded that, at many of the Maya sites, moon age was reckoned from the first visibility of the new crescent, an age of one day not being accorded until one full day had elapsed since the "birth" of the moon; but that at other sites an attempt was made to reckon from an estimated or computed conjunction time. (An alternative hypothesis would have the former sites attempting to reckon from conjunction, and the latter from the last visibility of the waning crescent, the "death" of the moon. This hypothesis has disadvantages which, in the opinion of the writer, outweigh its advantages: it would require the rejection of the best potential eclipse dates—observed or predicted—of which there are records; and it would necessitate discounting also the meaning or the relevance of the "birth" sign that appears as the principal constituent of the hieroglyph glossing moon ages at some sites belonging to the first of these categories.)

It has been assumed that some of the recorded moon ages were actual records of observation; but many of them may have been—and some of them must have been—the results of computation. In monuments in which the date of the initial passage is the most recent, and in which further content pertains to prior events, that initial date can probably be regarded as approximately contemporary with the erection of the monument and its moon age could perhaps be the permanent record of a lunar observation. In others, in which the date of the initial passage is one of many years prior to the last date of the inscription, or to the date of erection of the monument, unless there was available a log of observations reaching considerable distances back into the past (of which no specimens have survived in any form) the recorded moon ages may have been the products of computation. And in the cases of mythological dates that reach thousands of years back into past time, the recorded moon ages must of necessity be the results of computation. The subject of these computations is discussed below in "Eclipse Reckoning"; for the eclipse-reckoning tables were surely employed also as a general reckoning device for moon ages. And there is good evidence that the cycle on which eclipse reckoning was premised was a discovery that long antedated the table of the Dresden Codex.

The place of the moon in the lunar half-year is another datum in which there was variability from site to site and from time to time. Prior to about 9.12.15.0.0 (which would be A.D. 687 according to a chronological correlation accepted by some) there was variability among the sites. From this time, however, until about 9.16.5.0.0 (A.D. 756 in this correlation) there was uniformity. After that time there was variability again. A grouping of moons into half-years would seem to have only two possible motivations deriving from natural phenomena: either to relate the moons to the recurrence of eclipse seasons, or to relate them approximately to the halves of the tropical year as determined by the equinoxes or by the solstices. In the former case, half-years are usually of six months but sometimes of five; in the latter they are usually of six but sometimes of seven. Thus, the latter is ex-

cluded for the Maya groupings, because their moon numbers never exceed six. If the motivation was the former, uncertainty and variability are well understandable (see "Eclipse Reckoning"). Curiously, during the period of uniformity a standard six-month lunar half-year was adopted and spread the length and breadth of the area of Classic Maya civilization, with uniform numbering of the moons. This can have related to no natural phenomenon and must have been either an arbitrary convention or one born of an erroneous theory that took some seventy years to discredit. The date of the beginning of the gradual abandonment of this method is of interest. According to the Dresden Codex, 9.16.4.10.8 appears to be the initial epoch for the system there presented, although that particular recension and arrangement must pertain to an epoch some 300 years later. The close proximity of this date to the first abandonment of the uniform system of moon numbers in inscriptions is perhaps not an accident. Yet, the knowledge of that eclipse cycle, of 405 lunations to 11,960 days, must be considerably older. It was definitely used at Palenque just prior to 9.14.10.4.2 (*circa* A.D. 725) in an interesting piece of numerology (see "Numerology," below), and the same ratio was used also at Palenque about 9.13.0.0.0 (*circa* A.D. 692) to compute moon ages attributed to mythological dates of 1.18.5.4.0, 1.18.5.3.6, and −6.14.0 (the first two *circa* 2360 B.C., and the third *circa* 3120 B.C.).

Thus it appears that a proper theory may already have been in existence—perhaps even from the beginning of the recording of moon numbers, which was at least as early as 8.16.0.0.0 (A.D. 357)—and that something more persuasive than convenience or theory may have been behind the rapid spread of the seemingly ill-conceived uniform system. It has been supposed that it may reflect an episode in the political history of the area—a hypothesis that will require new testing, now that more potential evidence is coming to light both from archaeology and from advances in the understanding of the inscriptions.

The remaining item of lunar data associated with the initial date of a monument is that of the moon's duration (glyph *A*). This was a calendrical rather than an observational matter. The problem is not a trivial one for a lunar calendar, and so should be stated. A simple alternation of 30-day and 29-day months must be broken from time to time, so as to allow for more of 30 days than of 29, since the mean length of the lunar month is greater than 29½ days, namely, 29.530588 days. The optimum arrangement is one that provides for two 17-month groups followed by one 15-month group [2(17) + 1(15)], each group beginning and ending with a 30-day month, with the alternation thus being broken at the junctures of the groups where two 30-day months come in immediate succession. The resulting ratio is one of 49 lunar months to 1,447 days [(26 × 30) + (23 × 29)], which is equivalent to a mean lunation of 29.530612 days. There are other arrangements with other ratios that are workable, but none as good as this for relatively short-term determinations. It is not known how many Maya solutions there were to this problem. One, which was employed at Copán, in what is now Honduras, involved a ratio of 149 moons to 4,400 days [(79 × 30) + (70 × 29)], equivalent to a mean lunar month of 29.530201 days—good enough for relatively short spans of time, but not one of the best (it is eighth-best among such possibilities), and not good enough to be accurate for the long-range use to which it was applied. It has not been determined how the astronomers of Copán arrived at this ratio, or on what theory it was based. Its arrangement of moons however, as required for the problem of glyph *A*, requires seven 17-month groups and two 15-month groups, each group beginning and ending with a 30-day month, possibly in the sequence [4(17)+ 1(15)+ 3(17)+ 1(15)], but with other compromises and *ad hoc* arrangements possible also.

Another ratio, employed at Palenque, can be expressed as 81 moons to 2,392 days, equivalent to a mean lunar month of 29.530864 days. Neither is this among the best possibilities (it is sixth-best, erring in the opposite direction from that of Copán), and it too was not good enough to provide accuracy for the long-range projections in which it was used, up to almost four millennia. (Of course the Palenque astronomers could not have known this, as neither could those of Copán have known of the deficiency in theirs; but had they known, it is quite apparent that it would have been a matter of concern.) The theory behind the Palenque ratio, unlike that of Copán, is known; it is derived from the eclipse cycle of 405 lunations to 11,960 days, which is the same ratio. The arrangement of the sequence of 30-day and 29-day months in this scheme is governed in part by the structure of the eclipse cycle, which introduces considerations extraneous to the simple problem of finding a suitable arrangement for a lunar calendar. (These matters are treated in "Eclipse Reckoning.")

The fact that the juxtaposition of two 30-day months in immediate succession was governed by a theoretical scheme of some sort is illustrated by the occurrence of such a sequence in a projection

far back into mythological antiquity at Palenque, in a pair of dates just fourteen days apart. To the earlier of the pair, 1.18.5.3.6, the initial date of the Temple of the Sun, is ascribed a moon number of 4, a moon age of 26 days, and a lunar month duration of 30 days. To the later one, 1.18.5.4.0, the initial date of the Temple of the Foliated Cross, is ascribed the moon number of 5, a moon age of 10 days, and month duration again of 30 days. Since these were backward projections of a little over three millennia at the time they were made, they are necessarily the products of computation according to some theory; and at this juncture in the theoretical scheme—perhaps codified as a table of arrangements within a cycle—two successive 30-day months were prescribed.

Questions not entirely settled are whether the moon number (glyph *C*) and the moon duration (glyph *A*) pertain to the current lunar month or to the preceding one. For example, in regard to moon number, is "moon 4, age 26" in the Temple of the Sun intended to mean that on that date 26 days have been completed in the fourth moon of the current half-year, or that 4 moons and 26 days have been completed? Is it 3 lunar months and 26 days, or 4 lunar months and 26 days that have passed? Crucial cases for a decisive test are elusive. The same is true for the question of lunar month duration. Were it not for the circumstance that *both* of the above-mentioned inscriptions specify 30-day durations, they would have provided a crucial test. The interval between the dates is 14 days. If 14 days are added to moon age 26 with moon number 4, which are the data of the earlier date, then a moon age of either 10 or 11 days with moon number 5 is reached for the second date, depending on whether the moon just completed was of 30 or of 29 days. But the recorded moon age for the second date is 10 days, so the moon just completed was of 30 days. If the data with the earlier date had prescribed a duration of 29 days and that with the later had prescribed 30, then it would be known that the prescriptions referred to the last completed month. Had the reverse been the case, it would be known that they referred to the current month. But since both are 30, the question remains unanswered. (This is the pair of dates that enabled John Teeple [about 1924] to decipher the meanings of the hieroglyphs pertaining to the lunar calendar.) Related to these uncertainties is the question of whether any recorded moon ages at all were actually the products of current observation, or whether they too were prescriptions of a lunar calendar. The role of observations may have been to develop a theory and to attempt to perfect the lunar calendar, while the recording of moon ages could well have been by calendrical prescription in all cases. These, and the theories and practices that must be seen to lie behind them, varied from site to site, except during the "period of uniformity."

The moon's behavior appears to have been a subject of ongoing research and perhaps of fundamental disagreements among the Classic Maya astronomers. To most of us it must seem that they did remarkably well (see also "Eclipse Reckoning"). Why, for example, should we care what is beyond the third decimal point in the figures for the mean duration of the lunar month which are equivalent to the Maya ratios, especially when they lacked decimal (or vigesimal) fractions? A comparison of their achievements can be expressed in another way. Employment of the Copán ratio accumulates an error of one full day (negative) in a little less than 209 years. Employment of the Palenque ratio accumulates an error of one full day (positive) in slightly less than 293 years. They had not discovered the optimum short-range ratio mentioned first in this discussion, employment of which accumulates an error of one full day (positive) only after nearly 3,369 years. This would have been suitable to the time spans over which they attempted predictions. Somewhere and at some time, perhaps wherever the Dresden Codex came from, and perhaps in the early postclassic period, it appears that a means was discovered for making periodic corrective adjustments to the lunar calendar based on the eclipse cycle that accomplished a double purpose, namely, to preserve an important relationship between that cycle and the almanac, and to make possible far more accurate long-range reckonings of the moon. If we can believe that the apparent applications of this device in the relations between certain dates in the Dresden Codex were not merely fortuitous, then they attest to a method having a precision such that the accumulation of an error of one full day (negative) would require nearly 4,492 years. (This topic is touched on further, although briefly, in "Eclipse Reckoning.")

IV. THE VENUS CALENDAR

Pages 46–50 of the Dresden Codex contain the table shown here in Figure 1. Its division into five periods of 584 days each identify it as a table of the synodic years of Venus. The further subdivisions of these into intervals of 236, 90, 250, and 8 days, can be assumed to represent the canonical values

ascribed by the Maya to the periods of Morning Star, Superior Conjunction, Evening Star, and Inferior Conjunction, respectively, of that planet.[12]

The 584-day figure is the average of the approximate lengths of the synodic periods of Venus in a cycle of five, which, to the nearest whole day, are of 580, 587, 583, 583, and 587 days, respectively. It approximates closely the true mean value of 583.92 days. The eight days ascribed to inferior conjunction are a fair approximation to a mean value for a period of invisibility that can vary from a couple of days to a couple of weeks. As for the other subdivisions, they are of appropriate orders of magnitude, although more nearly equal intervals might have been anticipated for the two periods of visibility. A reason for the slight disproportion is not readily apparent, although considerations of lunar reckoning (236 days are eight lunar months, 250 are about eight and a half), or of canonical days chartered by myth, have been suggested as possibilities.

Since the Maya calendar year was of 365 days (without leap year corrections), and since 365 and 584 share a common factor of 73, a cycle of five Venus years coincides with a cycle of eight Maya calendar years. The length of this combined cycle is 2,920 days, or 8.2.0 in Maya calendrical numerals. This is the accumulation of days after one procession through the five pages of the table. It is recorded as such on page 50, in the black number of the fourth column in the middle section of that page.

The 260-day sacred almanac is not contained without remainder in this five-Venus-year/eight-calendar-year cycle. Its veintena component, 20, is contained in 2,920, but its trecena component, 13, is not. Hence it requires thirteen processions through the five pages of the table to return to the same day in the sacred almanac. The almanac days of the stations in this greater cycle are given in the thirteen lines of the top sections of the five pages of the table. The veintena days (represented by their hieroglyphic signs) repeat line after line, but the trecena days (the numerical coefficients) vary. The length of the greater cycle is 13 times 2,920, or 37,960 days, which is equal to two calendar rounds, or 65 approximate synodic years of Venus, or 104 Maya calendar years.

The calendrical and numerical data are found in the first four columns (the left-hand half) of each of the five pages of the table. Certain other items are also included. From top to bottom, the left-hand halves of the pages display the following information.

Upper Section: thirteen lines of positions in the 260-day almanac, twenty per line (four on each page), naming the almanac days reached by adding the cumulative totals (black numbers, bottom of middle section) to a base, or starting point, falling on almanac day *1 Ahau*.

Middle Section: (1) a line of positions in the 365-day year, naming the year days reached by adding the same cumulative totals to a base falling on year day *13 Mac*; (2) a line of repetitions of a constant "event" glyph, repeated in each of the twenty columns; (3) a line of direction glyphs, north, west, south, and east, repeated in this order on each of the five pages; (4) a line of name glyphs of "gods," variable, with only a single repetition in the line of twenty; (5) a line of "Venus" glyphs, in two variant but equivalent forms—so-called half and full—twenty in all; and (6) a series of black two-place and three-place numerals, giving the cumulative totals of the intervals specified by numbers in red at the bottom of each page (see below).

Lower Section: (1) a second line of positions in the 365-day year, naming the year days reached by adding the cumulative totals to a base falling on year day *18 Kayab*; (2) a line of repetitions of a second constant "event" glyph—in line 3 on page 46, omitted on page 47, and in line 2 on pages 48 to 50—different from the "event" glyph of middle section line 2; (3) a line of variable name glyphs of "gods," the same ones (a few with variant but equivalent glyph forms) and in the same order as those of middle section line 4, but offset one column to the right—in line 2 on pages 46 and 47, in line 3 on pages 48–50; (4) a second line of constant "Venus" glyphs, only in the "full" variant—omitted on page 48; (5) a line of direction glyphs, in the same order as in line 3 of the middle section, but offset one column to the right, thus reading east, north, west, south; (6) a third line of positions in the 365-day year, naming the year days reached by adding the cumulative totals to a base falling on year day *3 Xul*; and (7) a series of two-place numerals, in red, naming the intervals 11.16, 4.10, 12.10, and 0.8, which are equal to 236, 90, 250, and 8 respectively, specifying the canonical durations of the four subdivisions of the Venus year.

The right-hand sides of the five pages are given over to astrological interpretations, pictorially illustrated, and to prognostications associated with each of the five calendrical varieties, or celestial regions, of heliacal risings of Venus. The upper illustrations are of deities seated on celestial thrones consisting of bands of planetary and astral signs. They are the deities named in the five "east" posi-

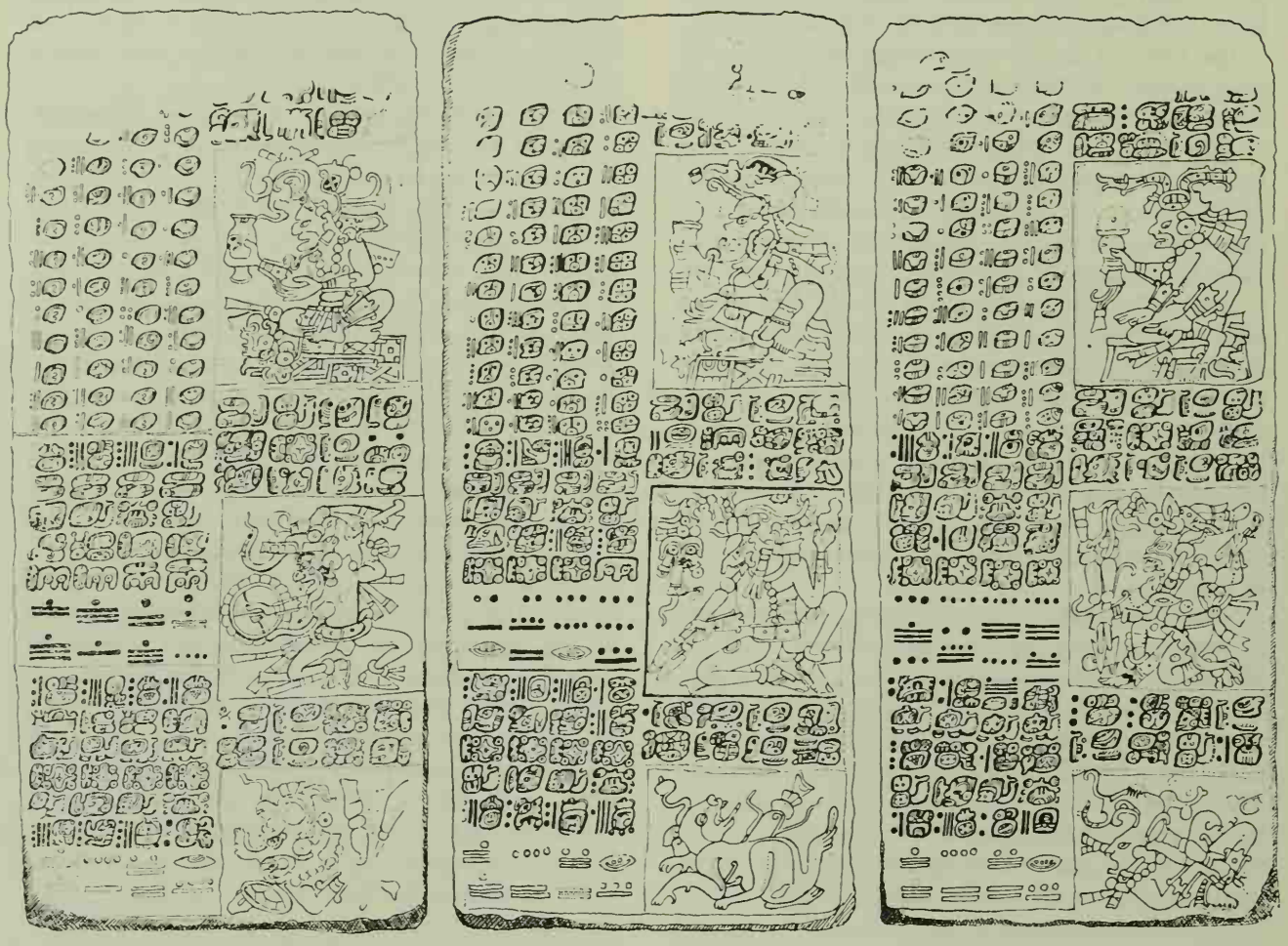
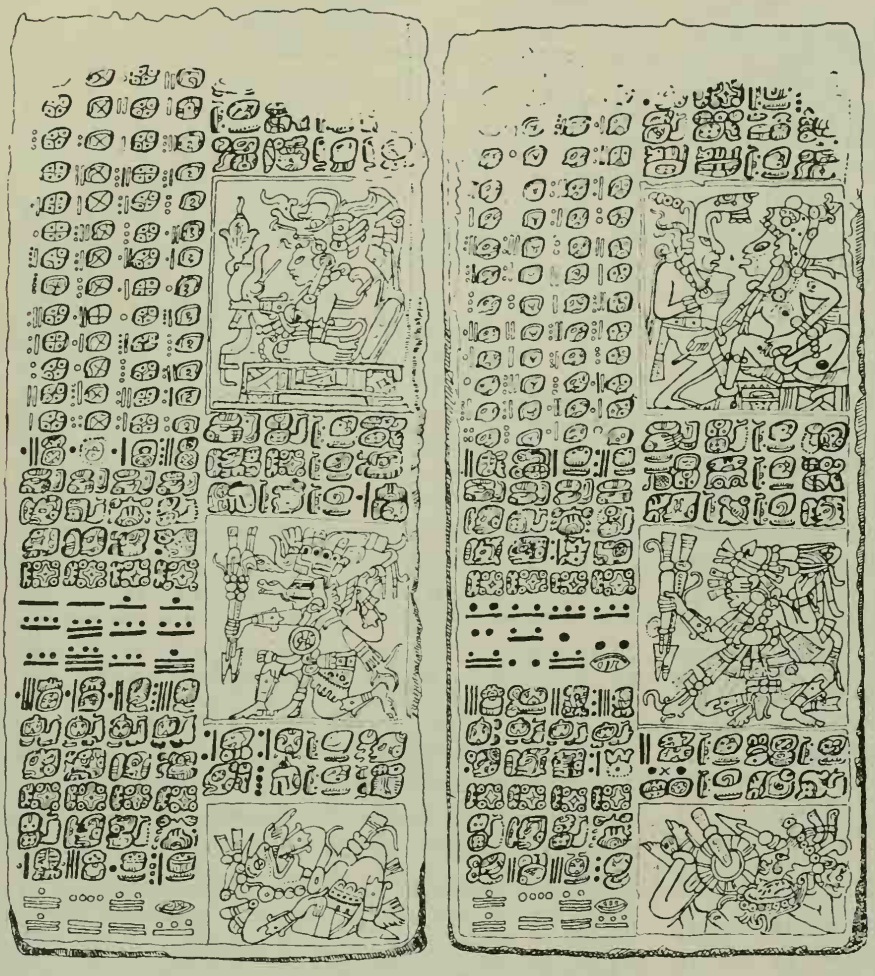


FIGURE 1. Pages 46–50 of the Dresden Codex.

tions in the two lines of god names on the left-hand sides of the pages. (The name of the deity pictured on any given page is found in the first column of the lower section of that same page, and in the fourth column of the middle section of the preceding page.) The iconography seems to warrant their being regarded as presiding figures in the different celestial regions in which heliacal risings of the planet take place. The middle illustrations are of deities equipped with instruments of warfare (shield, spears, spear thrower). They are assumed, on the basis of analogy with information contained in Mexican ethnohistorical sources, to represent the guises or manifestations of Venus at each of its canonical heliacal risings. The shafts emanating from the Morning Star on these occasions were said to have "speared," each time, a different order of victims. The lower illustrations are of deities or other symbolic figures that represent the primary victims, each being shown pierced, or about to be pierced, with a spear. The illustrations are accompanied with hieroglyphic annotations. These name the various protagonists in the drama, the "spearing" event, the prognostications of ill, and the categories of other things, personages, and deities susceptible to misfortune on these occasions. The six glyphs in the first pair of columns over the middle picture of each page state the following kinds of information:

Event glyph ("appear"?)	"East" (*lakin*)
Name of spearer (variable)	"Venus" (*chac ek*)
Name of victim (variable)	"his spearing" (*u hul*).

Thus, on page 46 this sequence can be interpreted,



49 50

quite in accord with Maya grammar, as follows: "Appears in the east, god *L* as Venus; god *K* is the object (the victim) of his spearing." Similarly, but with other protagonists, on the other pages.

The calendrical and numerical content of the left-hand portions of the pages, excluding all other matters, are transcribed in Table 1. The first thirteen lines present the trecena positions (the coefficients of the day signs) from the first thirteen lines of the Dresden Codex table. Effaced portions at the tops of the pages of the codex are restored in the transcription. The veintena days, which are constant for each column and are repeated redundantly in the codex, are indicated only once in the transcription, in line 14, by means of numerals according to the scheme of the table of "Days of the Veintena" (p. 781). Year days, from the three alternative sets provided in the codex table, are given in the transcription by their numerical equivalents, Maya fashion, in lines 15, 16, and 17. Thus, for example, the number "6" standing over the number "4" in the first entry in line 15 (corresponding to column *A* on page 46 of the codex) represents the Maya numeral otherwise transcribed as 6.4, meaning "six score and four," that is, the 124th day of the year. This is the day *4 Yaxkin*, as recorded in this position in the first line of year days in the Maya table. Direct conversion from the Maya name of any day of the year to its numerical equivalent, or vice versa, can be made by filling in its day-of-the-month number in the appropriate blank in the table of "Months of the Year" (p. 781); conversion to Arabic follows then from reading the first of the two digits as scores

Table 1. Calendrical and Numerical Data From the Venus Table of the Dresden Codex.

Line no.	Category of information	Page 46				Page 47				Page 48				Page 49				Page 50			
		A	*B*	*C*	*D*	*A*	*B*	*C*	*D*	*A*	*B*	*C*	*D*	*A*	*B*	*C*	*D*	*A*	*B*	*C*	*D*
1	Trecena day	3	2	5	13	2	1	4	12	1	13	3	11	13	12	2	10	12	11	1	9
2	" "	11	10	13	8	10	9	12	7	9	8	11	6	8	7	10	5	7	6	9	4
3	" "	6	5	8	3	5	4	7	2	4	3	6	1	3	2	5	13	2	1	4	12
4	" "	1	13	3	11	13	12	2	10	12	11	1	9	11	10	13	8	10	9	12	7
5	" "	9	8	11	6	8	7	10	5	7	6	9	4	6	5	8	3	5	4	7	2
6	" "	4	3	6	1	3	2	5	13	2	1	4	12	1	13	3	11	13	12	2	10
7	" "	12	11	1	9	11	10	13	8	10	9	12	7	9	8	11	6	8	7	10	5
8	" "	7	6	9	4	6	5	8	3	5	4	7	2	4	3	6	1	3	2	5	13
9	" "	2	1	4	12	1	13	3	11	13	12	2	10	12	11	1	9	11	10	13	8
10	" "	10	9	12	7	9	8	11	6	8	7	10	5	7	6	9	4	6	5	8	3
11	" "	5	4	7	2	4	3	6	1	3	2	5	13	2	1	4	12	1	13	3	11
12	" "	13	12	2	10	12	11	1	9	11	10	13	8	10	9	12	7	9	8	11	6
13	" "	8	7	10	5	7	6	9	4	6	5	8	3	5	4	7	2	4	3	6	1
14	Veintena day	16	6	16	4	20	10	20	8	4	14	4	12	8	18	8	16	12	2	12	20
15	Year day (*a*)	6	10	4	5	17	3	15	16	9	14	8	9	2	7	1	1	13	18	12	12
		4	14	19	7	3	8	18	6	17	7	12	0	11	1	6	14	10	0	5	13
16	Year day (*b*)	10	14	9	9	3	7	1	2	14	0	12	13	6	11	5	5	17	4	16	16
		*9	*19	4	12	3	13	18	6	2	7	17	5	16	6	11	19	15	0	10	18
17	Year day (*c*)	16	3	15	16	9	14	8	8	2	6	1	1	13	17	12	12	*6	10	4	5
		19	4	14	2	13	3	8	16	7	17	2	10	6	16	1	9	0	10	15	3
18	Cumulative totals			1	1	2	2	3	3	3	4	4	4	5	5	6	6	7	7	8	8
		11	16	10	11	5	9	4	4	16	2	15	15	9	13	8	8	2	7	1	2
		16	6	16	4	0	10	0	8	*4	14	4	12	8	18	8	16	12	2	12	0
19	Increments	11	4	12	0	11	4	12	0	11	4	12	0	11	4	12	0	11	4	12	0
		16	10	10	8	16	10	10	8	16	10	10	8	16	10	10	8	16	10	10	8

NOTE: The four numbers with prefixed asterisks are corrections of scribal copying errors.

and the second as units, and interpreting the result. Finally, the cumulative totals in the progression through the five-Venus-year cycle, and the increments contributing to those totals—which are the black numbers and the red numbers respectively of the codex table—are transcribed directly in lines 18 and 19.

The three alternative bases, in the order of their listing in the table, are the calendar-round days (*a*) *1 Ahau 13 Mac*, (*b*) *1 Ahau 18 Kayab*, and (*c*) *1 Ahau 3 Xul*—respectively (1, 20, 12.13), (1, 20, 16.18), and (1, 20, 5.3) in Maya numerical equivalents, or (1, 20, 253), (1, 20, 338), and (1, 20, 103) in Arabic. Their common almanac position, *1 Ahau*, is the last one in the Maya table, at the end of the thirteenth line of these on page 50, column *D*. Their three alternative positions in the Maya year are at the ends of the three lines of year-day data, also on page 50, column *D*. Since it is a reentering table, these end points are also its beginning points or "bases."

Since the table has three alternative bases and three corresponding alternative series of year days marking the phenomena of Venus, it is in effect three tables, each self-contained and complete. The implication must be that they were designed to replace one another. The motive for replacement can have come only from the obsolescence, or anticipated obsolescence, of a single table. Obsolescence is the inevitable result of the small discrepancy previously noted between the length of the canonical Venus year of 584 days and the true mean value of the period over longer spans of time, namely, 583.92 days. The error, of 0.08 days per Venus year, accumulates to one of 5.2 days in the 65 Venus years (104 calendar years) covered by the

Days of the Veintena, With Numerical Equivalents

1 = Imix
2 = Ik
3 = Akbal
4 = Kan
5 = Chicchan
6 = Cimi
7 = Manik
8 = Lamat
9 = Muluc
10 = Oc
11 = Chuen
12 = Eb
13 = Ben
14 = Ix
15 = Men
16 = Cib
17 = Caban
18 = Etznab
19 = Cauac
20 = Ahau

table. This, however, is still within the range of variability and ambiguity in the beginnings and endings of the periods of visibility of the planet. For the accumulation of error to pose an acute problem might have required more than one run through the table. But toward the end of a second run it would surely have been perceived as critical. Heliacal risings, on an average, would then be coming about ten days ahead of the prescribed calendrical positions. Correction would be in order. To make a correction of five days, for example, at the end of one run of the table, or of ten days at the end of two, would require a complete rewriting of the table; for the base position in the almanac would no longer be at *1 Ahau*, but at a day somewhat prior to that, say *9 Men* for a five-day correction, or *4 Oc* for one of ten days. Yet the base day provided by the Maya table remains at *1 Ahau* in each of the three recorded alternatives. This suggests that the day *1 Ahau* was somehow sacrosanct as the day for a Venus epoch—which is known, in fact, to be true: "One-Ahau" was the calendrical name of the mythical hero who "became" Venus. It also implies that corrections were accomplished not by making small foreshortenings of the table in amounts equal to the magnitude of the perceived error, but rather by making foreshortenings of whatever magnitude might be required to locate another almanac day *1 Ahau*, somewhere in the cycle, that would come satisfactorily close to coincidence with a heliacal rising. (The alternative, that error be allowed to accumulate until it amounts to the length of the almanac, 260 days, is excluded not only by the impracticality of carrying along an error of such magnitude, but also by the length of time that it would take for it to accrue—fifty runs of the table, or a little over five millennia. It is also excluded by the particular choices of year days specified for the *1 Ahau* bases in the codex.)

The choice of year days assigned to the three alternative bases must provide a clue as to the manner of introducing corrections into the table, as well as to the order in which the alternative bases, and the table premised on them, were to succeed one another. With three such, there are three possible pairings and six permutations. The corresponding minimal intervals between members of ordered pairs are as follows (employing the letters *a*, *b*, and *c*, as in the second paragraph above, for the alternative bases *1 Ahau 13 Mac*, *1 Ahau 18 Kayab*, and *1 Ahau 3 Xul*, in their order of listing in column *D*, codex page 50; and letting *ab* designate the interval from *a* to *b*; *ac* the interval from *a* to *c*; *bc* that from *b* to *c*; and so forth):

"Months" of the Year, With Conversion of Year Days to Numerical Equivalents

Number of prior months completed
↓ Day in current month (supply)
↓ ↓ Name of current month
↓ ↓ ↓ (ordinal number)

0. ___ Pop (first month)
1. ___ Uo (second)
2. ___ Zip (third)
3. ___ Zotz (fourth)
4. ___ Tzec (fifth)
5. ___ Xul (sixth)
6. ___ Yaxkin (seventh)
7. ___ Mol (eighth)
8. ___ Chen (ninth)
9. ___ Yax (tenth)
10. ___ Zac (eleventh)
11. ___ Ceh (twelfth)
12. ___ Mac (thirteenth)
13. ___ Kankin (fourteenth)
14. ___ Muan (fifteenth)
15. ___ Pax (sixteenth)
16. ___ Kayab (seventeenth)
17. ___ Cumhu (eighteenth)
18. ___ Uayeb (remainder)

Reading Down

(1) *ab*: 19.9.0, or 7,020 days
(2) *ac*: 2.6.4.0, or 16,640 days
(3) *bc*: 1.6.13.0, or 9,620 days

Reading Up

(4) *ba*: 1.13.4.0, or 11,960 days
(5) *ca*: 6.9.0, or 2,340 days
(6) *cb*: 1.6.0.0, or 9,360 days

The second three are the calendar-round complements of the first three. That is to say, the sum of the first and the fourth is equal to 2.12.13.0, or 18,980 days, the length of the calendar round; and so also is the sum of the second and the fifth; and that of the third and the sixth. This follows from the definition of *minimal* intervals. (For the method of computation of intervals between calendar-round days, see "Calendar, Chronology, and Computation.")

Three of these intervals share the property of being an integral multiple of 6.9.0, or 2,340. The fifth (*ca*) is equal to that quantity, the first (*ab*) is its third multiple, and the sixth (*cb*) is its fourth multiple. The other intervals do not contain this factor. Thus the fifth, the first, and the sixth intervals form a proper set, while the second, the fourth, and the third form a complementary set. These hold more promise of being significant sets than do the ones tabulated above, which were premised on spatial arrangement of the bases on page 50 of the codex. The common-factor criterion realigns them as follows:

Set I, Multiples of 2,340

(5) *ca*: 6.9.0, or 2,340 days
(1) *ab*: 19.9.0, or 7,020 days
(6) *cb*: 1.6.0.0, or 9,360 days

Set II, Not Multiples of 2,340

(2) *ac*: 2.6.4.0, or 16,640 days
(4) *ba*: 1.13.14.0, or 11.960 days
(3) *bc*: 1.6.13.0, or 9,620 days

In set I both occurrences of *c* are initial, both of *b* are final, while one instance of *a* is final and the other initial. Therefore the sequence of bases in set I is necessarily *c*, *a*, *b*, and the interval *cb* is the sum of the intervals *ca* and *ab*. By a similar argument the proper sequence for the set II ordering is shown to be *b*, *a*, *c*, and the interval *bc* is the sum of *ba* and *ac* (modulo 2.12.13.0, or 18,980). Thus the order of replacement of the bases, whichever of these two orders it be, is not the order of their vertical alignment in the codex.

It should now be noted that 2,340 is equal to 4×585, that is, to four synodic years of Venus plus four days. It is also equal to 9×260, which means that any increment or decrement in this amount, or in any multiple of this amount, will preserve a given position in the almanac. These two facts point to the significance of the intervals of set I. Any one of these quantities, if subtracted from the *1 Ahau* terminal day of the table, will locate another *1 Ahau* in the table, that much prior to its termination, which will be respectively 4, 12, or 16 days earlier in relation to a mean time of heliacal rising of Venus than would be the terminal *1 Ahau*. Thus, it locates a potential new base, for a new Venus epoch, which will effect a 4-day, 12-day, or 16-day correction of accumulated error.

The intervals determined above were the minimum intervals for the six possible permutations of the calendar-round days recorded as alternative bases. Now it can be seen that only for three of these permutations, those of set I, are minimum intervals the relevant ones. Those of set II cannot be relevant, because they lead respectively to days *1 Ahau* which are 296, 304, and 308 days prior to expected heliacal rising, rather than 4, 12, and 16 days. This is because the length of the complete Venus table is equal to two calendar rounds, not one. Thus, the intervals for the permutations of set II should be derived by subtracting those of set I from two calendar rounds (not from just one), or from some multiple of two calendar rounds.

If the interval *ca*, 6.9.0 or 2,340 days, the smallest of set I, is subtracted from two calendar rounds, that is, from 5.5.8.0 or 37,960 days, the complementary interval *ac*—that is, from *1 Ahau 13 Mac* to *1 Ahau 3 Xul*—will be 4.18.17.0, or 35,620 days. This is equal to 61 times 584, less 4 days. In 61 Venus years, reckoned at 584 days each, the accumulated error reaches 4.88 days. The almanac day reached is *5 Kan* (page 46 of the codex, line 13, column *D*). By stopping four days short of *5 Kan*, the almanac day *1 Ahau* is reached, and the accumulated error is reduced from 4.88 to 0.88 days. Thus, it is appropriate that the interval 6.9.0, the shortest of set I, be subtracted from two calendar rounds, that is, from the length of the full Venus table. This locates a more suitable day *1 Ahau* for a new Venus epoch than would be the one at the end of the table. But it has a different year day, that is, *3 Xul* instead of *13 Mac*.

*n*CR	Numerical equivalent	Complement of 1.6.0.0	Same in Arabic	Same in V, less days	Error in days	Correction	Residual error
2CR	5. 5. 8.0	3.19. 8.0	28,600	49V − 16d	3.92	−16	−12.08
4CR	10.10.16.0	9. 4.16.0	66,560	114V − 16d	9.12	−16	− 6.88
6CR	15.16. 6.0	14.10. 6.0	104,520	179V − 16d	14.32	−16	− 1.68
8CR	1.1.1.14.0	19.15.14.0	142,480	244V − 16d	19.52	−16	+ 3.52

If now the interval *cb*, 1.6.0.0 or 9,360 days, the largest of set I, also is subtracted from two calendar rounds, the complementary interval *bc*—that is, from *1 Ahau 18 Kayab* to *1 Ahau 3 Xul*—will be 3.19.8.0 or 28,600 days. This is equal to 49 times 584, less 16 days. In 49 canonical Venus years the accumulated error reaches 3.92 days. Thus it is not appropriate that 1.6.0.0 be subtracted from two calendar rounds, for it would overcorrect, substituting an error of −12.08 days for one of +3.92 days. The appropriate complement to 1.6.0.0, then, should be that obtained by subtracting it from some larger even-numbered multiple of the calendar round. The possibilities are enumerated in the tabulation at the head of this page.[13] The optimum is obviously the six-calendar-round complement. The interval *bc* then—that is, from *1 Ahau 18 Kayab* to *1 Ahau 3 Xul*—will be 14.10.6.0, or 104,520 days, which is equal to 179 times 584, less 16 days. In 179 canonical Venus years the accumulated error reaches 14.32 days. The almanac day reached is *4 Cib* (page 49 of the codex, line 10, column 4). By stopping sixteen days short of *4 Cib*, a day *1 Ahau* is reached, and the accumulated error is reduced from 14.32 days to −1.68 days. But this *1 Ahau* falls on year day *3 Xul* rather than on *18 Kayab*.

The above determination of the magnitudes of intervals *ac* and *bc* of set II results also in the determination of *ba*, for it has been shown that the proper sequence for set II is *b*, *a*, *c*, and that *bc* is the sum of *ba* and *ac*. The interval *ba*, therefore, is equal to the difference between *bc* and *ac*. This interval, the apparently intended length of time from *1 Ahau 18 Kayab* to *1 Ahau 13 Mac*, must then be 9.11.7.0, or 68,900 days, which is equal to 118 times 584, less 12 days. In 118 canonical Venus years the accumulated error reaches 9.44 days. The almanac day reached is *13 Eb* (page 48 of the codex, line 11, column 4). By stopping twelve days short of *13 Eb*, a day *1 Ahau* is reached, and the accumulated error is reduced from 9.44 days to −2.56 days. Such overcorrections, one supposes, might have been balanced in the long run by successive applications of the 6.9.0 foreshortening, which undercorrects in the amount of 0.88 days. Three of these would be the appropriate number.

Since the 16-day correction inherent in the greatest of these intervals is equal to the sum of the 12-day and 4-day corrections inherent in the two lesser ones, and since the intervals themselves stand in a similar relationship, the question arises whether the 12-day correction might not also be resolved into the sum of an 8-day and a 4-day correction, these being made separately and sequentially. Inasmuch as the interval that effects a 12-day correction is equal to four calendar rounds less 19.9.0, the two separate intervals effecting 8-day and 4-day corrections would be, respectively, two calendar rounds less 13.0.0, and two calendar rounds less 6.9.0. These are the intervals 4.12.8.0

1 Ahau 18 Kayab	to	1 Ahau 8 Yax:	4.18.17.0	or	35,620	(=2CR − 6.9.0)
+ 1 Ahau 8 Yax	to	1 Ahau 13 Mac:	4.12. 8.0	or	33,280	(=2CR − 13.0.0)
= 1 Ahau 18 Kayab	to	1 Ahau 13 Mac:	9.11. 7.0	or	68,900	(=4CR − 19.9.0)
+ 1 Ahau 13 Mac	to	1 Ahau 3 Xul:	4.18.17.0	or	35,620	(=2CR − 6.9.0)
= 1 Ahau 18 Kayab	to	1 Ahau 3 Xul:	14.10. 6.0	or	104,520	(=6CR − 1.6.0.0)
or:						
1 Ahau 18 Kayab	to	1 Ahau 18 Uo:	4.12. 8.0	or	33,280	(=2CR − 13.0.0)
+ 1 Ahau 18 Uo	to	1 Ahau 13 Mac:	4.18.17.0	or	35,620	(=2CR − 6.9.0)
= 1 Ahau 18 Kayab	to	1 Ahau 13 Mac:	9.11. 7.0	or	68,900	(=4CR − 19.9.0)
+ 1 Ahau 13 Mac	to	1 Ahau 3 Xul:	4.18.17.0	or	35,620	(=2CR − 6.9.0)
= 1 Ahau 18 Kayab	to	1 Ahau 3 Xul:	14.10. 6.0	or	104,520	(=6CR − 1.6.0.0)

(33,280 days) and 4.18.17.0 (35,620 days). No further resolution is possible, since each of these is a foreshortening of just two calendar rounds, that is, of one run through the Venus table. Depending on which of these might precede the other, one or the other of the two sequences tabulated at the bottom of page 783 is anticipated.

The last three lines of either of these sequences present the inferred intervals (the optimal ones) between the bases recorded on page 50 of the codex. The potential intermediate bases presented in the top pairs of lines in the two alternative sequences are not recorded on that page. They are hypothetic possibilities, either *1 Ahau 8 Yax* or *1 Ahau 18 Uo*.

Pages 46–50 of the Dresden Codex would have been known as pages 25–29 if the screenfold manuscript had not become unhinged and separated into two parts, or if it had been realized when pagination was assigned that the two parts were once joined. The five pages of the Venus table were immediately preceded by another (before the separation), this being page 24, which contains related and prefatory material. This page, and a transcription of it, are reproduced here as Figure 2.

The page contains a table of multiples of 8.2.0 (2,920) on the right, with other numerals intrusive in the fourth of the five tiers; and on the left is a chronological matter, with hieroglyphic annotations. As is usual in tables of multiples in the codex, the lowest number, of which the others are multiples, is in the lower right-hand corner. Reading is from right to left in any tier, and from bottom to top in passing from tier to tier. This is contrary to the left-to-right and top-to-bottom reading, in pairs of columns, which is otherwise standard.

The number 8.2.0, or 2,920 (equal to 5×584) is that which is recorded also on page 50, column *D*, at the end of the line of cumulative totals (the black numbers of the codex, or line 18 of the transcription in Table 1). In its occurrence on page 24, it stands over the sign of the almanac day *9 Ahau*. The base or zero day for the table, then, is *1 Ahau*, for the addition of 8.2.0 to *1 Ahau* yields *9 Ahau*. The second number is 16.4.0, the second multiple of 8.2.0, and the day recorded below it is *4 Ahau*. Thus, the first through the fourth multiples are recorded in the bottom tier, the fifth through the eighth in the second tier, and the ninth through the twelfth in the third tier. The trecena coefficients of the *Ahau* days reached by these twelve intervals are 9, 4, 12, 7, 2, 10, 5, 13, 8, 3, 11, and 6, and are so recorded. This is the same series of trecena coefficients that is found prefixed to the first twelve *Ahau* signs of column *D* of page 50 of the codex. The series terminates there with *1 Ahau* on the thirteenth line. Thus, the thirteenth multiple of 8.2.0, namely, 5.5.8.0, standing over a *1 Ahau*, would be anticipated to follow also in this series on page 24. The *1 Ahau* is there, but 5.5.8.0 is not. The numerals of the fourth tier are not multiples of 8.2.0. But the expected number is found in the fifth tier. Although partially obliterated, sufficient remains of the numerals in this topmost tier to identify them as 5.5.8.0, 10.10.16.0, 15.16.6.0, and 1.1.1.14.0, which are 13th, 26th, 39th, and 52nd multiples of 8.2.0. These are 2, 4, 6, and 8 calendar rounds, respectively, or the first four multiples of the number of days covered by the entire table of pages 46–50.

Two of the numerals in the intrusive fourth tier are already familiar. One of these, 4.12.8.0, is the doubly foreshortened cycle (2CR−13.0.0) that effects an eight-day correction. It is equal to 57 Venus years less 8 days. Proceeding from the *1 Ahau* base of the table of pages 46–50, an increment of 57 Venus years leads to the day *9 Lamat* (page 47, line 12, column *D*). By stopping eight days short of *9 Lamat*, a day *1 Ahau* is reached for a new Venus epoch, effecting a correction of eight days against the accumulated lag of the table behind the planet. If the application is to the base *1 Ahau 18 Kayab*, it leads to *1 Ahau 18 Uo*. It will be noted that a day *1 Ahau 18 Uo* is recorded on page 24 of the codex, at the bottom of the third column on the left-hand side. This was one of the two alternative hypothetic possibilities previously noted for the intermediate base.

The next numeral in the fourth tier, 9.11.7.0, is also familiar. It is the sum of one doubly foreshortened cycle (2CR−13.0.0) and one singly foreshortened cycle (2CR−6.9.0), which together make up the triply foreshortened double cycle (4CR−19.9.0) that provides for a twelve-day correction and that, as already seen, best mediates between *1 Ahau 18 Kayab* and *1 Ahau 13 Mac*. Assuming that these numbers are indeed to be applied to *1 Ahau 18 Kayab*, which is the earliest of the alternative bases recorded in the table, they constitute supporting evidence for the second of the alternative sequences posited above. An additional singly foreshortened cycle then leads to *1 Ahau 3 Xul*.

The remaining two numerals in this tier are new, in that neither of them has been implied in any way by the content of pages 46–50 of the codex. The first of these, 1.5.5.0, is equal to 9,100 days. If it is applied, as were the others, to *1 Ahau 18 Kayab*, it

	A	B	C				
1	1 Ahau	18 Kayab	4 Ahau	260 V = 8 CR	195 V = 6 CR	130 V = 4 CR	65 V = 2 CR
2		Event 'B'	8 Cumhu	1			
3		VENUS	Event 'B'	1	15	10	5
4	East	Event 'A'	Spearer p. 46	14	16	10	5
5	VENUS	Regent p. 48	VENUS	0	6	16	8
6	Venus	Regent p. 49	Spearer p. 47	1 Ahau	0	0	0
7	VENUS	Regent p. 50	Venus	10 CR −8 (V+1)	1 Ahau	1 Ahau	1 Ahau
8	Venus	Regent p. 46	Victim p. 46	1	4 CR −12 (V+1)	2 CR −8 (V+1)	16 (V+1) −13.0
9	VENUS	Regent p. 47	Victim p. 47	5	9	4	1
10	Ill Omen		Victim p. 48	14	11	12	5
11	,,		Victim p. 49	4	7	8	5
12	,,		Victim p. 50	0	0	0	0
13		2340 V = 72 CR	LC Day Number	1 Ahau	1 Ahau	1 Ahau	1 Ahau
14		9	9	60 V	55 V	50 V	45 V
15		9	9	4	4	4	3
16				17	9	1	13
	RN	16	9	6	4	2	0
	6	0	16	0	0	0	0
	2			6 Ahau	11 Ahau	3 Ahau	8 Ahau
	0	0	0	40 V	35 V	30 V	25 V
				3	2	2	2
				4	16	8	0
				16	14	12	10
				0	0	0	0
	4 Ahau	1 Ahau	1 Ahau	13 Ahau	5 Ahau	10 Ahau	2 Ahau
				20 V	15 V	10 V	5 V
				1	1		
				12	4	16	8
				*8	6	4	2
				0	0	0	0
	8 Cumhu	18 Kayab	18 Uo	7 Ahau	12 Ahau	4 Ahau	9 Ahau

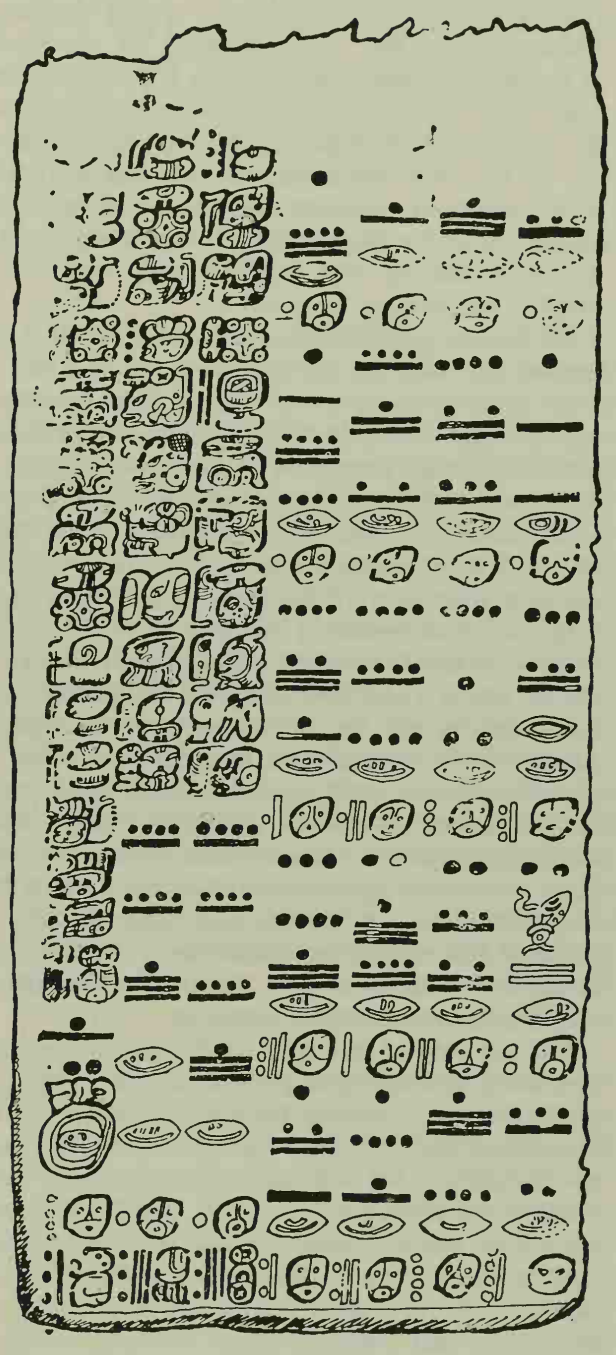


FIGURE 2. Page 24 of the Dresden Codex with transcription.

leads to a day *1 Ahau 13 Pax*; but, unlike those, it falls nowhere near a heliacal rising of Venus. This number is equal to 15 Venus years plus 340 days. It leads to a day that is 14 days after the *13 Cimi* of page 46, line 4, column *B*, and is thus 14 days after the expected or scheduled beginning of the Evening Star period of that Venus year. If the number that was intended here is that which is written, and if it is to be applied to the same base as are all of the others, then its purpose must be

something different from the purpose of the others, which was to approximate as best as possible the *Ahau* heliacal risings of Venus and the optimal *1 Ahau* positions for new Venus epochs and new starts through the table. Nothing is recorded in the glyphic annotations on the left side of the page that offers any clue as to what phenomenon this date may have reference to. Neither is a year day *13 Pax* recorded in any of these pages. There is no generally accepted interpretation of this number or of the day to which it apparently leads. An accompanying oral tradition may once have supplied the missing information.

The last of the numbers of this tier, 1.5.14.4.0, if applied to *1 Ahau 18 Kayab*, leads again to a day *1 Ahau 18 Uo*; but it is one that is eight calendar rounds later (1.1.1.14.0) than that attained by 4.12.8.0. The accumulation of error in eight calendar rounds, or four unabridged runs through the entire table, is 20.8 days. It is not likely, then, that two such days, separated from each other by eight calendar rounds, were both intended to be designated as Venus epochs. (The interval 1.5.14.4.0 is 17.36 days longer than 317 mean Venus periods of 583.92 days.) These two numbers, the second and the fourth in this tier (counting from the right), were either to be applied to two different bases *1 Ahau 18 Kayab*, eight calendar rounds apart, not both reckoned as heliacal risings of Venus, and were to lead to the same *1 Ahau 18 Uo*; or else they were to be applied to the same *1 Ahau 18 Kayab* and were to lead to two different days *1 Ahau 18 Uo*, not both of which were to be counted as days of heliacal rising of Venus. The first alternative is the one generally accepted.

The left side of this page of the codex is given over to the chronological placement of an event, or pair of events, seemingly having to do with the institution of the corrective mechanism for the Venus calendar. The data are arrayed in three columns, to be labeled here as *A*, *B*, and *C*. In these the normal order of reading is followed in the hieroglyphic portion of the text, which is from left to right in pairs of columns, with any unpaired column being read singly. Columns *A* and *B* are thus paired, and column *C* follows. Considering the calendrical and chronological matters first, attention is directed to the numbers and days recorded in the lower left.

At the bottom of column *A* is *4 Ahau 8 Cumhu*, which is the calendrical position of day zero of the day count (something over three millennia B.C.). Over it stands the number 6.2.0 with a "ring"—a band of cloth, looped and knotted at the top—encircling its last digit. A number so marked is a negative base, at that distance prior to the beginning of the current era. Historical dates in the codex (presumably, but not assuredly, of some astronomical import) are most often reckoned from such negative bases rather than from chronological zero. The items determining such a date consist of the following: (1) a "ring number" standing over *4 Ahau 8 Cumhu*, giving the chronological position of the selected pre-zero base, these being at the bottom of the column if the whole is arrayed in one column, or at the bottom of the left-hand column if it is in two; (2) the calendrical position of the pre-zero base, this standing at the top of the column, or of the pair of columns; (3) a long reckoning or distance number, similar to a day number in the normal day count but applied to the special pre-zero base rather than to the normal base; (4) the calendrical position of the terminal date reached by applying the distance number to the pre-zero base, this following immediately the distance number and standing over the ring number if they are in one column, but at the bottom of the second column if they are in two; and (5), in some cases, glyphic annotation, inserted between (2) and (3) if in a single column, or between (2) and (1 and 3) if in two columns. In only one case, namely the present one, is there recorded also (6) the normal day number of the terminal date. This is near the bottom of column *C*, with the calendrical position of its base—the normal one, *4 Ahau 8 Cumhu*—standing at the top of that column, and with further glyphic annotations in between. The data recorded in the present example are tabulated below.

The special pre-zero base and the terminal date here have the same calendar day, which is frequently but not always the case with such reckonings. The standard place for the calendar day of the base is at the top of the column or pair of columns. These glyphs are obliterated on this page, but they can be restored with confidence on the basis of precedent and have been included in the transcription of the page. The calendar day of the terminal date also appears in its normal position, immediately below

(1*b*) Normal base, day zero of the day count: . . . . . *4 Ahau 8 Cumhu*
(1*a* and 2) Ring number and pre-zero base: − 6. 2.0, *1 Ahau 18 Kayab*
(3) Distance number applied to pre-zero base: 9.9.16. 0.0 (add)
(6 and 4) Terminal date, normal day number: 9.9. 9.16.0, *1 Ahau 18 Kayab*.

the distance number at the bottom of column *B*. It is not repeated at the bottom of column *C*, possibly because of its redundancy, or more likely because some place had to be found for the *1 Ahau 18 Uo*, which is required by two of the intervals already reviewed from the fourth tier on the right side of the page. In any case, the calendar day at the bottom of column *C* belongs with those intervals, and not with the day number above it.

Something of the motive for choosing negative ring number bases from which to reckon dates, rather than employing the normal base, can be detected in the nature of the distance numbers that are applied to them. These are contrived numbers. They are multiples of the values of various periods or cycles such as are in some way relevant to the commemorated date and event. They are, moreover, the smallest such multiples that will just exceed the normal day number. The date of a ring number base, then, is a like-in-kind to the historical date that is counted from it, inasmuch as it occupies the same position in one or several relevant calendrical cycles as does the historical date. And it is the last possible date that bears such a likeness in kind before the beginning of the current chronological era, that is, before *4 Ahau 8 Cumhu*, day zero of the current era, or the close of the preceding era. In the present case the date of the ring-number base and the historical date occupy the same positions in the 260-day almanac, the 365-day year, the 584-day canonical Venus year, a 2,340-day cycle that unites that of the almanac with that of the nine lords of the night and with a 117-day cycle pertaining to the rain god (besides being also the corrective foreshortening of the Venus great cycle), and various higher-order cycles deriving from these, such as the calendar round (18,980 days), the unabridged great cycle of Venus (37,960 days), and so forth. Thus:

$$\begin{aligned} 9.9.16.0.0 = 1{,}366{,}560 &= 5{,}256\ (260) \\ &= 3{,}744\ (365) \\ &= 2{,}340\ (584) \\ &= \quad 584\ (2{,}340) \\ &= \quad 468\ (2{,}920) \\ &= \quad\ 72\ (18{,}980) \\ &= \quad\ 36\ (37{,}960). \end{aligned}$$

The motive for commemorating the date 9.9.9.16.0, *1 Ahau 18 Kayab*, is less clear. It is the day of this same name coming eight calendar rounds later that is the best candidate for being the *1 Ahau 18 Kayab* heliacal rising of Venus in column *D*, page 50 of the codex. On this assumption, the chronology of these pages is as follows:

[13. 0. 0. 0. 0],	4 Ahau 8 Cumhu [day no., old era]
−6. 2. 0	(ring number)
[12.19.13.16. 0],	1 Ahau 18 Kayab [day no., old era]
+9. 9.16. 0. 0	(72 CR) [add; subtract 13 baktuns]
9. 9. 9.16. 0,	1 Ahau 18 Kayab [day no., current era]
+1. 1. 1.14. 0	(8 CR)
10.10.11.12. 0,	1 Ahau 18 Kayab
+4.12. 8. 0	(2 CR − 13.0.0)
10.15. 4. 2. 0,	1 Ahau 18 Uo
+4.18.17. 0	(2 CR − 6.9.0)
11. 0. 3. 1. 0,	1 Ahau 13 Mac
+4.18.17. 0	(2 CR − 6.9.0)
11. 5. 2. 0. 0,	1 Ahau 3 Xul.

The pivotal date is the third *1 Ahau 18 Kayab*, at 10.10.11.12.0. This and the following dates can be assumed to be deliberate approximations to heliacal risings of Venus, chosen as epoch days for new starts through the Venus calendar. The two earlier *1 Ahau 18 Kayab* dates appear to be numerological projections backward in time, as if the canonical length of the Venus year, 584 days, were to be assumed as accurate and valid before the pivotal date. After the pivotal date, however, it is no longer quite valid, and the corrective mechanism is instituted. That mechanism cuts short the great cycles of Venus by either of two amounts, 13.0.0 (equal to 4,680 days) or 6.9.0 (equal to 2,340 days), in order to locate days *1 Ahau* at or suitably close to heliacal rising for beginning new cycles. Only these two amounts are deducted from a single complete great cycle (two calendar rounds). Larger amounts, such as 19.9.0 and 1.6.0.0, result as sums of successive applications of the lesser corrections, in succeeding great cycles, and are consequently deductible from some higher even-numbered multiple of calendar rounds.

As a result of this corrective mechanism, the *1 Ahau* starting point of any new great cycle will be found close to the end of either the 57th or the 61st Venus year of the preceding cycle, rather than at the end of the 65th which formally completes the table. For the four-day correction this is four days before the *5 Kan* of line 13, column *D*, of codex page 46; and for the eight-day correction it is eight days before the *9 Lamat* of line 12, column *D*, of page 47. The next 236 days then lead from the one or the other of these directly to the *3 Cib* at the top of column *A* of page 46, bypassing the remainder of the table in line 13, or in lines 12 and 13.

The hieroglyphic commentary in column *C* of page 24 reflects this. In glyph-block *C*3 (column *C*, line 3) is an event glyph of common occurrence whose meaning and reading are still uncertain. This is followed in *C*4 and *C*5 by the name glyph of the

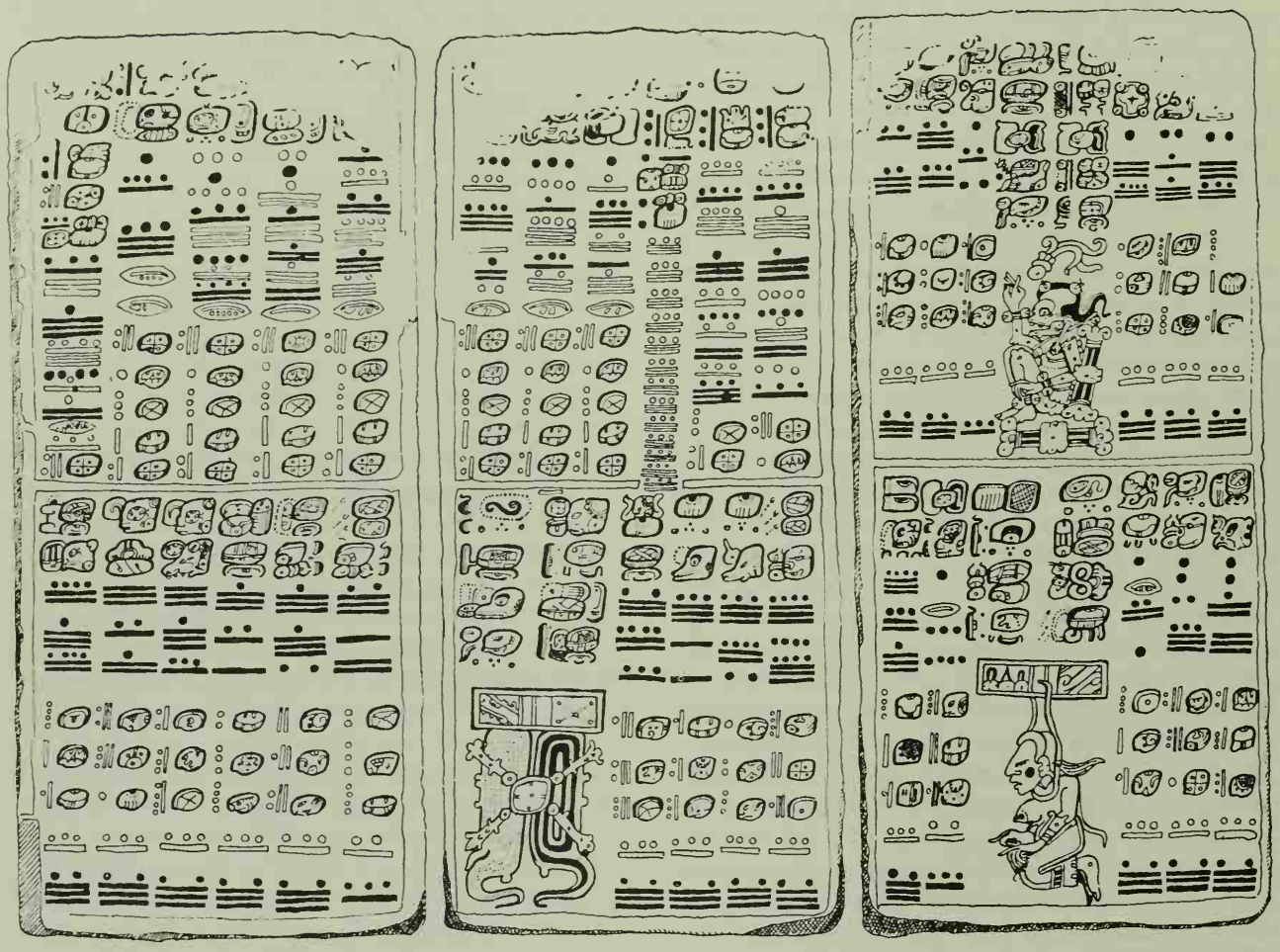
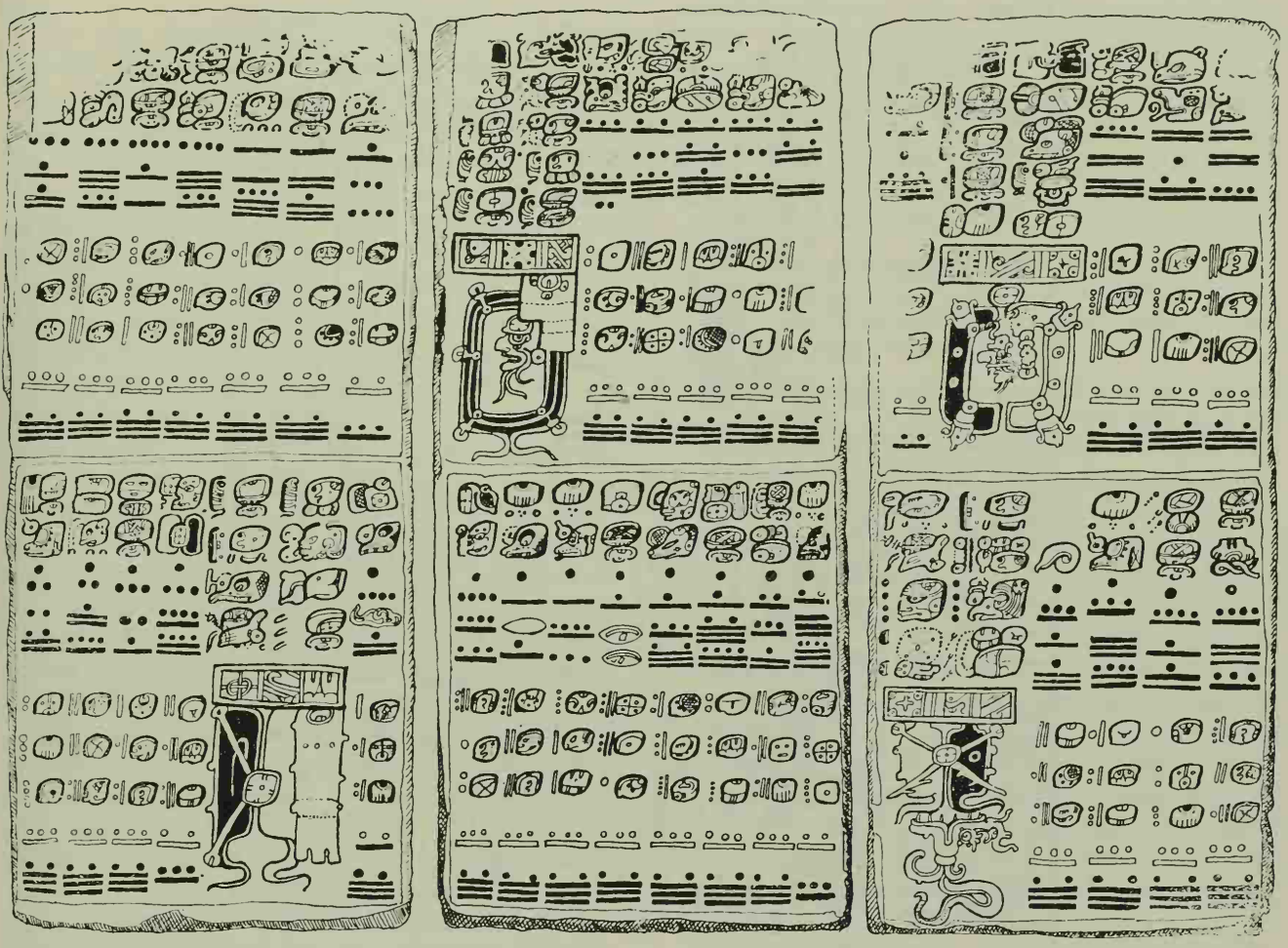


FIGURE 3. Pages 51–58 of the Dresden Codex

Venus deity—"The Spearer"—of the heliacal risings of page 46, qualified, as also on that page, by the Venus glyph that identifies his role. These are followed in turn, in *C*6 and *C*7, by the name glyph of the spearer of page 47, again with the Venus glyph. These two are the only spearing deities named here, but their appellatives are followed, in *C*8 to *C*12, by the names of all five of the victims of pages 46–50. This sequence, by both its context and its content, appears intended to apply to the 4.12.8.0 abridgment of the great cycle. This is the one that began on *1 Ahau 18 Kayab* and was terminated on *1 Ahau 18 Uo*, eight days prior to the *9 Lamat 6 Zip* of line 12, column *D*, of page 47 (the year day, *6 Zip*, is in the first line of the lower section, same column). The implication is that in this terminal short run only two of the spearing deities were to play their roles, but that none of the victims would escape. In columns *A* and *B* of page 24 there is also an oblique reflection of the termination of the cycle with page 47. In glyph-blocks *AB*5–9 the five presiding deities or "Venus regents" are named, but those of pages 46 and 47 are named last.

The *18 Kayab* base was probably obsolete and *18 Uo* already installed at the time of this recension of the table. The *13 Mac* and *3 Xul* bases would have been prescriptions for the future. There is no record of application or prescription of corrections beyond *3 Xul*. The device could of course have been reapplied indefinitely. The year day of each successive revised base for a single correction (four days) is 215 days later in the year calendar, or 150 days earlier, than the one before. For a double correction (eight days) one of these is skipped. The optimum mix of double and single corrections is



54 55 56

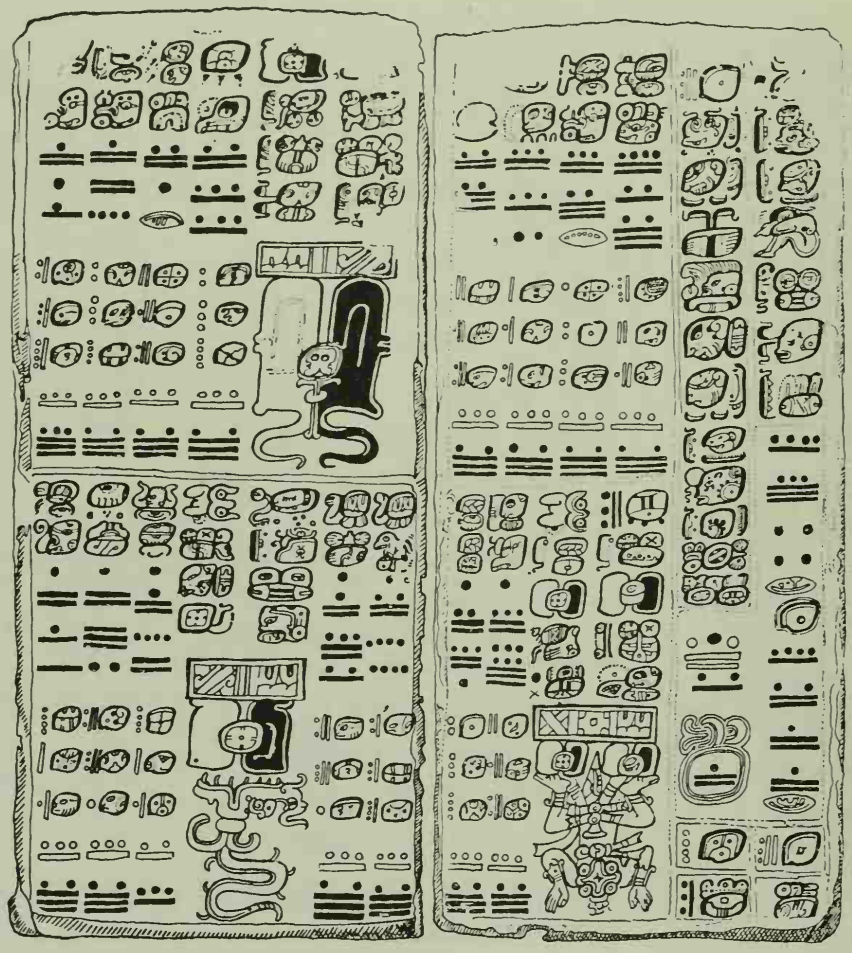
(continued on next page)

one to four. This ratio results in the assignment of 301 Venus years to (301 × 584) −24 days. The result is accurate to within 0.08 part of a day for this span of time, which is over 481 years. It yields a mean Venus year of 583.92026 days. The Maya calendar priests and star watchers were doubtless aware that they had a good scheme worked out for this planet, but one wonders whether they could have known how good it really is. (It should not be forgotten that they lacked fractional arithmetic.) Its long-term accuracy is of course greater than its short-term accuracy. But even for short terms the accumulated error never exceeds the magnitude of the deviation of the planet's actual periods from their mean value. The table was probably used as a warning table, geared to anticipate the phenomena, thus favoring negative errors over positive ones, or early predictions over late ones.

V. ECLIPSE RECKONING

Pages 51–58 of the Dresden Codex contain the table pictured here in Figure 3. Its division into intervals of 177 days (occasionally 178), and of 148 days, identifies it as a lunar table treating of groupings of six and of five lunar months. The number and distribution of the five-month periods among those of six months mark it moreover as having to do with the prediction of solar eclipse possibilities. There are nine of the five-month periods distributed among sixty of the six-month periods, these being in three major divisions of 23 groups each (20 of six months and 3 of five) for a total of 135 lunar months per division, or 405 months in all.[14] Data extracted from the Maya table are aligned in Table 2.

The structure of the eclipse table of the Dresden



57 58

Codex, and its implications, can be appreciated most readily if we set ourselves the task of constructing our own "primitive" solar-eclipse-prediction table. For this we require three items of information that can be derived from naked-eye observations and record keeping with a calendar, or inferred from an accumulation of such records, namely, the average length of the lunar month, the average length of the interval between lunar nodes, and the ecliptic limit for solar eclipses. Today we would use 29.530588 days for the first of these, 173.30906 for the second, and from 15 to 18 days for the last. The Maya, or at least some of them, used the ratio of 81 moons to 2,392 days for the first of these, three "nodes" to 520 days for the second (apparently with the understanding that these ratios, equivalent to 29.530864 and 173.33333 respectively, entailed small errors requiring correction as they accumulated), and it may be inferred that they used ±18 days for the last—although other and perhaps more plausible inferences may also be drawn from the numbers and their arrangement in the table of the Dresden Codex. While there is no need to quibble about differences between the Maya and our notions of "lunar month," it should perhaps be noted that the Maya concepts corresponding to "node" and "ecliptic limit" can hardly have entailed even the minimum understanding of celestial mechanics that is implied in our use of these terms; nor would they have needed to have such understanding. It was sufficient for them merely to have observed over time that eclipses, whether solar or lunar, never occurred except within three circumscribed sectors of their sacred 260-day almanac, and that these "eclipse-possible" periods came three times within

two rounds of that almanac, that is, three times in 520 days, their midpoints being 173 or 174 days apart.

For our experiment, however, let us use the modern figures and avail ourselves of the convenience of decimal fractions. But let us choose a slightly narrower hypothetic ecliptic limit, say 14.765 days, or one-half of the mean duration of a lunar month. This will be at little if any cost to the predictive capacity of the table in relation to its intended use, namely, as a predictor of "eclipse-possible" times (a warning table) for use at a tropical latitude. What is lost through this restriction of the ecliptic limit is the prediction of those eclipse possibilities that come at maximum distance from the nodes. In instances where it is possible for two solar eclipses to occur within the same eclipse season, one month apart, the one at the greater distance from the node will thus be eliminated from the table. The loss is of minimal consequence, since the probability of the excluded eclipse being visible in the tropics is virtually nil. (Such an eclipse is a partial eclipse of minimal magnitude, observable in either the far northern or the far southern latitudes, but rarely if ever within the tropics.)

The results of the experiment are tabulated in the first three columns of Table 3. Starting from a hypothetical lunar node passage, column 1 gives the times, in days and hundredths, of the next 69 nodes. The ordinal numbers of the nodes are ajjacent, in square brackets. In column 3, starting from a lunar-solar conjunction hypothetically coinciding with the node passage, are given the times of those successive conjunctions that fall within ±14.765 days of the enumerated node times of column 1. These are the "eclipse-possible" times, of which it is the function of the table to forewarn. The ordinal numbers of the lunations are adjacent, in square brackets. Column 2 gives the differences $(l - n)$ between the lunation times and the corresponding node times. Those eclipse times for which $(l - n)$ is less than about eleven days may be expected to correspond to central eclipses (total or annular) visible as such somewhere on the face of the earth. There is of course nothing in such a simple table to give an indication of the ranges of longitude or of latitude through which any given eclipse may be visible, except to the extent that the fractional parts of the numbers in column 3 may be employed as a rough guide to relative longitude for short-range predictions, and to the extent that low numbers in column 2 may offer a somewhat better-than-chance guide to probable visibility in the tropics.

The experimental table has been constructed for the purpose of offering a reference scheme against which the Maya scheme may be compared, in order better to understand the latter. Data from the Maya eclipse table of the Dresden Codex are translated and presented in Table 2. Some items of the data have also been transferred to Table 3, columns 6 and 7, with elaboration in columns 4 and 5, in order to facilitate comparison with the reference scheme that was derived from our experiment (columns 1–3). Before proceeding to the comparison, however, a word must be said about some problems encountered in the translation of the numerals from the Maya table.

The table of the Dresden Codex is not without imperfections. There are indications that it is not an original version, but a copy with revisions of an earlier version. There are a few rather gross errors that surely must be laid to faulty copywork. For instance, the very first number of the series of cumulative totals (the first Maya number in the upper series beginning on page 53*a* of the codex: see Figure 3) is written as 7.17. But obviously it should be 8.17, since the first cumulative total of the series must necessarily be the same as the first contribution to that total, which is written below as it should be, as 8.17, in the series of eclipse half-year intervals (same column, lower series of numbers, below the three lines of day signs). It is clear that one dot was omitted in the *uinal* or "scores" position by the copyist, which makes for an error of 20 days.

Another copying error on the same page of the codex is in the fourth cumulative total, written as 1.15.14; but this should be 1.15.19. It is obvious that one bar was omitted in the *kin* or "units" position by the copyist, resulting in an error of 5 days. And there are others, all of which are easily corrected.

There are two internal sources of evidence for every such correction, since the table is two ways redundant. The table could be reconstructed in its entirety from any one of three separate kinds of data contained in it, if the data of that kind were without error. As it is, the three kinds of data serve as checks on one another. They are (*a*) the series of intervals, mostly 8.17 or 7.8, equal to 177 and 148 days respectively, and corresponding to six-month and five-month eclipse half-years; (*b*) the series of cumulative totals, giving the day numbers, within the cycle, of the designated eclipse possibilities; and (*c*) the three series of day signs with numerical coefficients, naming the days in the 260-day almanac on which the respective eclipse possibilities

TABLE 2. Calendrical and Numerical Data from the Eclipse Table of the Dresden Codex.

1. Dresden Codex page number	2. Column number (=node number)	3. Cumulative totals as written in the Codex	4. Corrections required by indicated almanac days	5. Cumulative totals required by indicated almanac days, in Maya and in Arabic numerals [with cumulative month totals]		6. Day, from lower line of almanac days (with its number in the double almanac)	7. Increment
-----	(0)	----------		0	0 [0]	*13 Muluc (169)	-----
53a	1	7.17	1.0	8.17	177 [6]	8 Cimi (346)	177
	2	17.13	1	17.14	354 [12]	3 Akbal (3)	177
	3	1. 7. 2		1. 7. 2	502 [17]	8 Chuen (151)	148
	PICTURE						
	4	1.15.14	5	1.15.19	679 [23]	3 Lamat (328)	177
	5	2. 6.16		2. 6.16	856 [29]	*11 Chicchan (505)	177
	6	2.15.13		2.15.13	1,033 [35]	6 Ik (162)	177
54a	7	3. 6.11		3. 6.11	1,211 [41]	2 Ahau (340)	178†
	8	3.15. 8		3.15. 8	1,388 [47]	10 Caban (517)	177
	9	4. 6. 5		4. 6. 5	1,565 [53]	5 Ix (174)	177
	10	4.15. 8	−6	4.15. 2	1,742 [59]	13 Chuen (351)	177
	11	5. 5.19		5. 5.19	1,919 [65]	* 8 Lamat (8)	177
	12	5.10.16	4.0	5.14.16	2,096 [71]	3 Chicchan (185)	177
	13	6. 3. 4	1.0	6. 4. 4	2,244 [76]	8 Ben (333)	148
55a	PICTURE						
	14	8.13. 2	−2.0.0	6.13. 2	2,422 [82]	4 Chuen (511)	178†
	15	7. 3.18	1	7. 3.19	2,599 [88]	12 Lamat (168)	177
	16	7.12.16		7.12.16	2,776 [94]	7 Chicchan (345)	177
	17	8. 3.13		8. 3.13	2,953 [100]	* 2 Ik (2)	177
	18	*8.12.10		8.12.10	3,130 [106]	10 Cauac (179)	177
56a	19	*9. 1.18		9. 1.18	3,278 [111]	2 Manik (327)	148
	PICTURE						
	20	9.10.15		9.10.15	3,455 [117]	10 Kan (504)	177
	21	10. 1.12		10. 1.12	3,632 [123]	5 Imix (161)	177
	22	10.10. 9		10.10. 9	3,809 [129]	13 Extnab (338)	177
57a	23	11. 1. 6	1	11. 1. 7	3,987 [135]	9 Cib (516)	178†
	24	11.10. 4		11.10. 4	4,164 [141]	4 Ben (173)	177
	25	12. 1. 0	1	12. 1. 1	4,341 [147]	12 Oc (350)	177
	26	12. 8. 8	1	12. 8. 9	4,489 [152]	4 Etznab (498)	148
	PICTURE						
58a	27	12.17.*5	1	12.17. 6	4,666 [158]	12 Men (155)	177
	28	13. 8. 2	1	13. 8. 3	4,843 [164]	7 Eb (332)	177
	29	13.17. 0	1	13.17. 1	5,021 [170]	3 Oc (510)	178†
	30	14. 7.17	1	14. 7.18	5,198 [176]	11 Manik (167)	177
51b	31	14.16.14	1	14.16.15	5,375 [182]	6 Kan (344)	177
	32	15. 7.11	1	15. 7.12	5,552 [188]	1 Imix (1)	177
	33	15.16. 8	1	15.16. 9	5,729 [194]	9 Etznab (178)	177
	34	16. 7. 5	1	16. 7. 6	5,906 [200]	4 Men (355)	177
	35	16.16. 2	1	16.16. 3	6,083 [206]	12 Eb (12)	177
	36	17. 5.10	1	17. 5.11	6,231 [211]	4 *Ahau (160)	148
52b	PICTURE						
	37	17.14. 8	1	17.14. 9	6,409 [217]	13 Etznab (338)	178†
	38	18. 5. 5	1	18. 5. 6	6,586 [223]	8 Men (515)	177
	39	18.14. 2	1	18.14. 3	6,763 [229]	3 Eb (172)	177
	40	19. 4.19	1	19. 5. 0	6,940 [235]	11 Muluc (349)	177
53b	41	19.13.16	1	19.13.17	7,117 [241]	6 Cimi (6)	177
	42	1. 0. 3. 4	1	1. 0. 3. 5	7,265 [246]	11 Ix (154)	148
	PICTURE						
	43	1. 0.12. 1	1	1. 0.12. 1	7,442 [252]	6 Chuen (331)	177
	44	1. 1. 2.18	1	1. 1. 2.19	7,619 [258]	1 Lamat (508)	177
	45	1. 1.11.15	1	1. 1.11.16	7,796 [264]	* 9 Chicchan (165)	177
54b	46	1. 2. 2.12	1	1. 2. 2.13	7,973 [270]	4 Ik (342)	177
	47	1. 2.11. 9	1	1. 2.11.10	8,150 [276]	12 Cauac (519)	177
	48	1. 3. 2. 6	1	1. 3. 2. 7	8,327 [282]	7 Cib (176)	177
	49	1. 3. 9.14	1	1. 3. 9.15	8,475 [287]	12 Kan (324)	148

(continued on next page)

TABLE 2. Calendrical and Numerical Data from the Eclipse Table of the Dresden Codex *(continued)*.

1. Dresden Codex page number	2. Column number (=node number)	3. Cumulative totals as written in the Codex	4. Corrections required by indicated almanac days	5. Cumulative totals required by indicated almanac days, in Maya and in Arabic numerals [with cumulative month totals]		6. Day, from lower line of almanac days (with its number in the double almanac)		7. Increment
	PICTURE							
	50	1. 4. 0.11	1	1. 4. 0.12	8,652 [293]	7 Imix	(501)	177
55b	51	1. 4. 9. 8	1	1. 4. 9. 9	8,829 [299]	2 Etznab	(158)	177
	52	1. 5. 0. 6	1	1. 5. 0. 7	9,007 [305]	11 Cib	(336)	178†
	53	1. 5. 9. 3	1	1. 5. 9. 4	9,184 [311]	6 Ben	(513)	177
	54	1. 6. 0. 0	1	1. 6. 0. 1	9,361 [317]	1 Oc	(170)	177
	55	1. 6. 8.17	1	1. 6. 8.18	9,538 [323]	9 Manik	(347)	177
	56	1. 6.17.14	1	1. 6.17.15	9,715 [329]	4 Kan	(4)	177
	57	1. 7. 8.11	1	1. 7. 8.12	9,892 [335]	12 Imix	(181)	177
	58	1. 7.15.19	1	1. 7.16. 0	10,040 [340]	4 Muluc	(329)	148
56b	PICTURE							
	59	1. 8. 6.16	1	1. 8. 6.17	10,217 [346]	12 Cimi	(506)	177
	60	1. 8.15.14	1	1. 8.15.15	10,395 [352]	8 Kan	(164)	178†
	61	1. 9. 6.11	1	1. 9. 6.12	10,572 [358]	3 Imix	(341)	177
	62	1. 9.15. 8	1	1. 9.15. 9	10,749 [364]	11 Etznab	(518)	177
57b	63	1.10. 6. 5	1	1.10. 6. 6	10,926 [370]	6 Men	(175)	177
	64	1.10.15. 2	1	1.10.15. 3	11,103 [376]	1 Eb	(352)	177
	65	1.11. 4.10	1	1.11. 4.11	11,251 [381]	6 Ahau	(500)	148
	PICTURE							
	66	1.11.13. 7	1	1.11.13. 8	11,428 [387]	1 Caban	(157)	177
	67	1.12. 4. 4	1	1.12. 4. 5	11,605 [393]	9 Ix	(334)	177
58b	68	1.12.13. 1	1	1.12.13. 2	11,782 [309]	4 Chuen	(511)	177
	69	1.13. 3.18	1	1.13. 3.19	11,959 [405]	12 Lamat	(168)	177

NOTE: Prefixed asterisks in column 6 mark reconstructions of missing, illegible, or obviously erroneous data where adjacent items supply the necessary information.

may fall. No one of these is wholly free from errors; but the triple series of almanac days has the fewest and, but for a single case, offers the surest guide to the intended intervals and the proper cumulative totals.

Column 3 of Table 2 lists the cumulative totals in Maya numbers as written in the codex. Column 4 gives the corrections that are required to bring these into accord with the indicated almanac days. Column 5 gives the corrected totals, in both Maya and Arabic numerals, together with the count of lunations. Column 6 lists the almanac days (from the third of the three lines of these in the codex) and, in parentheses, their numerical equivalents in the 520-day double almanac. Column 7 gives the proper increments, as determined by the almanac days of column 6.

Points of interest in a comparison of the Maya table with the experimental one will be the following: (1) the structures of the two tables, as seen in the groupings of moons into eclipse half-years and of half-years into divisions of the cycle; (2) the magnitude of the ecliptic limits and the location of the nodes in the Maya table, as compared with those of the experiment; (3) the relevance of the pictures to their places of insertion in the Maya table; and (4) the degree of correspondence between the Maya computations and our own. Other matters to be considered are (5) the distribution of 30-day and 29-day months in the lunar calendar; (6) the preface to the Maya table; and (7) correction devices to compensate for small accumulations of error.

1. The Structures. In the experimental table (columns 2–3 of Table 3) a pattern can be observed in the groupings of moons into eclipse half-years, and of half-years into divisions of the cycle. Beginning after the first five-month half-year (after 23 lunations, column 3), which is after the first drop in the abnodal-distance function (that is, *after* the first negative number in column 2), the grouping of moons is as follows:

seven groups of six, and one of five;
seven groups of six, and one of five;
six groups of six, and one of five;

for a total of 135 moons, in 23 groups, corresponding to that many nodes, and spanning a period of 3,986 and approximately 2/3 days. On repetition of the 135-month scheme, the arrangement found in the third line of the above ("six groups of six, and

TABLE 3. Tabulations of eclipse syzygies, restricted to one per node, (*a*) as determined by hypothetic ±14.765-day ecliptic limit, and (*b*) as selected in Dresden Codex; with dividing lines after each drop in abnodal-distance function, corresponding to picture dividers in Codex.

(*a*) Selection for ±14.765-day Ecliptic Limit					(*b*) Selection Corresponding to Dresden Codex				
1. Nodes: Days	[No.]	2. Abnodal Distances	3. Lunations: Days	[No.]	4. Abnodal Distances	5. Lunations: Days	[No.]	6. $a_n - a_0$	7. Δa
0.00	[0]	0.00	0.00	[0]	0.00	0.00	[0]	-----	-----
173.31	[1]	+ 3.87	177.18	[6]	+ 3.87	177.18	[6]	177	177
346.62	[2]	+ 7.75	354.37	[12]	+ 7.75	354.37	[12]	354	177
519.93	[3]	+11.62	531.55	[18]	−17.91	502.02	[17]	502	148
693.24	[4]	−14.04	679.20	[23]	−14.04	679.20	[23]	679	177
866.55	[5]	−10.16	856.39	[29]	−10.16	856.39	[29]	856	177
1,039.86	[6]	− 6.29	1,033.57	[35]	− 6.29	1,033.57	[35]	1,033	177
1,213.17	[7]	− 2.42	1,210.75	[41]	− 2.42	1,210.75	[41]	1,211	178†
1,386.48	[8]	+ 1.46	1,387.94	[47]	+ 1.46	1,387.94	[47]	1,388	177
1,559.79	[9]	+ 5.33	1,565.12	[53]	+ 5.33	1,565.12	[53]	1,565	177
1,733.10	[10]	+ 9.20	1,742.30	[59]	+ 9.20	1,742.30	[59]	1,742	177
1,906.41	[11]	+13.08	1,919.49	[65]	+13.08	1,919.49	[65]	1,919	177
2,079.72	[12]	−12.58	2,067.14	[70]	+16.95	2,096.67	[71]	2,096	177
2,253.03	[13]	− 8.71	2,244.32	[76]	− 8.71	2,244.32	[76]	2,244	148
2,426.34	[14]	− 4.83	2,421.51	[82]	− 4.83	2,421.51	[82]	2,422	178†
2,599.65	[15]	− 0.96	2,598.69	[88]	− 0.96	2,598.69	[88]	2,599	177
2,772.96	[16]	+ 2.92	2,775.88	[94]	+ 2.92	2,775.88	[94]	2,776	177
2,946.27	[17]	+ 6.79	2,953.06	[100]	+ 6.79	2,953.06	[100]	2,953	177
3,119.58	[18]	+10.66	3,130.24	[106]	+10.66	3,130.24	[106]	3,130	177
3,292.89	[19]	+14.54	3,307.43	[112]	−14.99	3,277.90	[111]	3,278	148
3,466.20	[20]	−11.12	3,455.08	[117]	−11.12	3,455.08	[117]	3,455	177
3,639.51	[21]	− 7.25	3,632.26	[123]	− 7.25	3,632.26	[123]	3,632	177
3,812.82	[22]	− 3.37	3,809.45	[129]	− 3.37	3,809.45	[129]	3,809	177
3,986.13	[23]	+ 0.50	3,986.63	[135]	+ 0.50	3,986.63	[135]	3,987	178†
4,159.44	[24]	+ 4.37	4,163.81	[141]	+ 4.37	4,163.81	[141]	4,164	177
4,332.75	[25]	+ 8.25	4,341.00	[147]	+ 8.25	4,341.00	[147]	4,341	177
4,506.06	[26]	+12.12	4,518.18	[153]	−17.41	4,488.65	[152]	4.489	148
4,679.37	[27]	−13.54	4,665.83	[158]	−13.54	4,665.83	[158]	4,666	177
4,852.68	[28]	− 9.66	4,843.02	[164]	− 9.66	4,843.02	[164]	4,843	177
5,025.99	[29]	− 5.79	5,020.20	[170]	− 5.79	5,020.20	[170]	5,021	178†
5,199.30	[30]	− 1.92	5,197.38	[176]	− 1.92	5,197.38	[176]	5,198	177
5,372.61	[31]	+ 1.96	5,374.57	[182]	+ 1.96	5,374.57	[182]	5,375	177
5,545.92	[32]	+ 5.83	5,551.75	[188]	+ 5.83	5,551.75	[188]	5,552	177
5,719.23	[33]	+ 9.70	5,728.93	[194]	+ 9.70	5,728.93	[194]	5,729	177
5.892.54	[34]	+13.58	5,906.12	[200]	+13.58	5,906.12	[200]	5,906	177
6,065.85	[35]	−12.08	6,053.77	[205]	+17.45	6,083.30	[206]	6,083	177
6,239.16	[36]	− 8.21	6,230.95	[211]	− 8.21	6,230.95	[211]	6,231	148
6,412.47	[37]	− 4.33	6,408.14	[217]	− 4.33	6,408.14	[217]	6,409	178†
6,585.78	[38]	− 0.46	6,585.32	[223]	− 0.46	6,585.32	[223]	6,586	177
6,759.09	[39]	+ 3.41	6,762.50	[229]	+ 3.41	6,762.50	[229]	6,763	177
6,932.40	[40]	+ 7.29	6,939.69	[235]	+ 7.29	6,939.69	[235]	6,940	177
7,105.71	[41]	+11.16	7,116.87	[241]	+11.16	7,116.87	[241]	7,117	177
7,279.02	[42]	−14.50	7,264.52	[246]	−14.50	7,264.52	[246]	7,265	148
7,452.33	[43]	−10.62	7,441.71	[252]	−10.62	7,441.71	[252]	7,442	177
7,625.64	[44]	− 6.75	7,618.89	[258]	− 6.75	7,618.89	[258]	7,619	177
7,798.95	[45]	− 2.87	7,796.08	[264]	− 2.87	7,796.08	[264]	7,796	177
7,972.26	[46]	+ 1.00	7,973.26	[270]	+ 1.00	7,973.26	[270]	7,973	177
8,145.57	[47]	+ 4.87	8,150.44	[276]	+ 4.87	8,150.44	[276]	8,150	177
8,318.88	[48]	+ 8.75	8,327.63	[282]	+ 8.75	8,327.63	[282]	8,327	177
8,492.19	[49]	+12.62	8,504.81	[288]	−16.91	8,475.28	[287]	8,475	148
8,665.50	[50]	−13.04	8,652.46	[293]	−13.04	8,652.46	[293]	8,652	177
8,838.81	[51]	− 9.16	8,829.65	[299]	− 9.16	8,829.65	[299]	8,829	177
9,012.12	[52]	− 5.29	9,006.83	[305]	− 5.29	9,006.83	[305]	9,007	178†
9,185.43	[53]	− 1.42	9,184.01	[311]	− 1.42	9,184.01	[311]	9,184	177
9,358.74	[54]	+ 2.46	9,361.20	[317]	+ 2.46	9,361.20	[317]	9,361	177

(continued on next page)

TABLE 3. Tabulations of eclipse syzygies, restricted to one per node, (*a*) as determined by hypothetic ±14.765-day ecliptic limit, and (*b*) as selected in Dresden Codex; with dividing lines after each drop in abnodal-distance function, corresponding to picture dividers in Codex *(continued)*.

(*a*) Selection for ±14.765-day Ecliptic Limit					(*b*) Selection Corresponding to Dresden Codex				
1. Nodes:		2.	3. Lunations:		4.	5. Lunations:		6.	7.
Days	[No.]	Abnodal Distances	Days	[No.]	Abnodal Distances	Days	[No.]	$a_n - a_n$	Δa
9,532.05	[55]	+ 6.33	9,538.38	[323]	+ 6.33	9,538.38	[323]	9,538	177
9,705.36	[56]	+10.20	9,715.56	[329]	+10.20	9,715.56	[329]	9,715	177
9,878.67	[57]	+14.08	9,892.75	[335]	+14.08	9,892.75	[335]	9,892	177
10,051.98	[58]	−11.58	10,040.40	[340]	−11.58	10,040.40	[340]	10,040	148
10,225.29	[59]	− 7.71	10,217.58	[346]	− 7.71	10,217.58	[346]	10,217	177
10,398.60	[60]	− 3.83	10,394.77	[352]	− 3.83	10,394.77	[352]	10,395	178†
10,571.91	[61]	+ 0.04	10,571.95	[358]	+ 0.04	10,571.95	[358]	10,572	177
10,745.22	[62]	+ 3.91	10,749.13	[364]	+ 3.91	10,749.13	[364]	10,749	177
10,918.53	[63]	+ 7.79	10,926.32	[370]	+ 7.79	10,926.32	[370]	10,926	177
11,091.84	[64]	+11.66	11,103.50	[376]	+11.66	11,103.50	[376]	11,103	177
11,265.15	[65]	−14.00	11,251.15	[381]	−14.00	11,251.15	[381]	11,251	148
11,438.46	[66]	−10.12	11,428.34	[387]	−10.12	11,428.34	[387]	11,428	177
11,611.77	[67]	− 6.25	11,605.52	[393]	− 6.25	11,605.52	[393]	11,605	177
11,785.08	[68]	− 2.36	11,782.70	[399]	− 2.38	11,782.70	[399]	11,782	177
11,958.39	[69]	+ 1.50	11,959.89	[405]	+ 1.50	11,959.89	[405]	11,959	177

one of five") works its way forward. For three repetitions the pattern is:

7 (6) + 1 (5); 7 (6) + 1 (5); 6 (6) + 1 (5);
7 (6) + 1 (5); 6 (6) + 1 (5); 7 (6) + 1 (5);
7 (6) + 1 (5); 6 (6) + 1 (5); 7 (6) + 1 (5);

for a total of 405 moons, in 69 groups, corresponding to that many nodes, and spanning a period of approximately 11,960 days. The internal arrangement of this scheme is a familiar one, known from Babylonian astronomy of the Seleucid period and earlier. The first five subdivisions of the above nine constitute the saros.[15]

Attention should be given to the positions of the five-month periods in Table 3*a* (immediately above the horizontal dividing lines of columns 2 and 3). Note that they terminate only at those conjunction times that are closest to the *prenodal* ecliptic limit. This is important for our understanding of the significance of the location of the five-month periods in the Maya table, and of the pictures that follow them.

The Maya table deviates somewhat from the above pattern of month groupings. It is of the same length, and with the same major divisions (3 × 135 moons = 3 × 23 groups), but the internal arrangement of the divisions is a bit different. These may be seen either in Figure 3 or in Table 2, in the placement of the "picture" breaks, or in columns 4–7 of Table 3, in the placement of the horizontal dividing lines across those columns. Beginning after the first break (after the picture of the "death god" on page 53*a* of the codex) the scheme is as follows:

9 (6) + 1 (5); 5 (6) + 1 (5); 6 (6) + 1 (5);
9 (6) + 1 (5); 5 (6) + 1 (5); 6 (6) + 1 (5);
8 (6) + 1 (5); 6 (6) + 1 (5); 6 (6) + 1 (5).

This also totals 405 moons, in 69 groups, for approximately 11,960 days. (For explanation of the apparent cumulative total 1.13.3.18, or 11,958, see below.) Although the pattern deviates from what might have been anticipated on the basis of our experiment and on the basis of Babylonian precedents, it shares with these the features (*a*) that each of the three major divisions consists of 20 six-month and 3 five-month groups, and (*b*) that the breaks *following* the five-month periods, which are marked by insertion of the pictures into the table, come (mostly) at times that are at or fairly near a *prenodal* ecliptic limit. The deviations from the experimental pattern must necessarily have correlates in differing durations, and in variability of duration, of the eclipse seasons implicit in the Maya table.

2. Ecliptic Limits and Nodes. In our experimental table (Table 3, columns 1–3) the hypothetical ecliptic limit employed was one-half of a lunar month, or ±14.765 days, and the zero line for the table assumed a precise coincidence of a conjunction and a node passage for the starting point of the table. This, of course, is a somewhat rare happening, and we can have no *a priori* grounds for assuming that the Maya astronomers made a similar assumption for the construction of their table. In-

spection of the table, however, may reveal whatever assumption underlies it in this regard.

Column 6 of Table 2 gives the names of the almanac days from the lowest of the three lines of such in the Dresden Codex table, and in parentheses in the same column are their translations into ordinal positions within the double almanac of 520 days (= about 3 nodes). If these are retabulated into three columns, corresponding to the three eclipse seasons that are found within a 520-day period, it will then be seen that the outer limits of the first eclipse season are days 151 (*8 Chuen*) and 185 (*3 Chicchan*), those for the second are 327 (*2 Manik*) and 355 (*4 Men*), and those for the third are 498 (*4 Etznab*) and 12 [= 532 mod 520] (*12 Eb*). From these the durations of the apparent eclipse seasons may be determined (35 days, 29 days, and 35 days respectively) as well as their midpoints and the values of the ecliptic limits that they imply. These are: day 168 (*12 Lamat*) ± 17 days for the first season; day 341 (*3 Imix*) ± 14 days for the second; and day 515 (*8 Men*) ± 17 days for the third. The midpoint days, then, are the implied node days; and they are indeed properly spaced to be such: from *12 Lamat* to *3 Imix* is 173 days; from *3 Imix* to *8 Men* is 174 days; and from *8 Men* to *12Lamat* is again 173 days. (See "Calendar, Chronology, and Computation" for a method of computing the interval between any two almanac days.)

The end-day of the table is *12 Lamat* (day 168), one of the implied node days just mentioned. The table thus appears to end, as our experimental one began, with a hypothetic coincidence of a node day with a lunar-solar conjunction—in other words, with the optimum condition for a central solar eclipse. This is marked in the codex by the tenth or "extra" picture that is inserted into the table (the only one that is not immediately preceded by a five-month half-year). The table, begins, however, not with *12 Lamat* (day 168), but with *13 Muluc* (day 169). Although the starting day is not written at the beginning of the table (there being no "zero" column), it can be derived from the day names and numbers in the columns that follow. For example, *8 Cimi* (in column 1), less Maya 8.17, is *13 Muluc*; similarly *8 Chuen* (from column 3), less 1.7.2, is also *13 Muluc*; again, *10 Kan* (column 20), less 9.10.15, is *13 Muluc*; and so forth. Thus the table, as represented by any one of the three lines of day names, spans 11,959 days rather than the expected 11,960—that is, 1.13.3.19 rather than 1.13.4.0, the latter of which is equal to 23 double almanacs, or 46 × 260. That the recognized length of the Maya cycle was 11,960 days, however, is apparent from the table of multiples of 1.13.4.0 that precedes the eclipse table proper on pages 51–52*a* of the codex. The one-day foreshortening of the cycle in the table suggests that it may have represented the occasion of a shift from a previously effective *13 Muluc* base to a new one on *12 Lamat*, one day earlier in the almanac. Since 405 mean lunar months are about eleven one-hundredths of a day short of 11,960 days (see last line of Table 3), such a foreshortening of the cycle would be a necessity approximately every ninth time that the cycle is employed. Such a shift is also suggested by the relationship between two of the dates that figure importantly in these pages. The earlier of the two is 9.12.10.16.9, *13 Muluc 2 Zip* (defined, on page 58 of the codex, by the interval 9.12.11.11.0 reckoned from a *13 Muluc* "ring" base of minus 12.11); the other is 9.16.4.10.8, *12 Lamat 1 Muan*, recorded as such on page 52*a*, as well as by means of a 9.16.4.10.0 increment to a *12 Lamat* reckoning base of plus 8, on page 51a). The interval between these two dates is 3.13.11.19, or 26,519 days. It is an eclipse interval, equal to two full eclipse cycles plus the lesser eclipse interval of 2,599 days (Maya 7.3.19, see column 5 of Table 2); it is about half a day in excess of 898 mean lunations, and about two and a half days in excess of 153 mean intervals. Whether either of these two dates was the occasion of an eclipse observed by the Maya is not known. They could have been; one or both may have been; but the possibility that one or both of them may have been the products of computation—perhaps for use as proximate reckoning bases—cannot be excluded.

The three rows of almanac days, with one-day intervals between successive rows, are also compatible with the hypothesis of a periodic one-day regressive shift of the base of the cycle. A *13 Muluc* line appears to have been superseded by a *12 Lamat* line; and future regressive shifts to *11 Manik* and *10 Cimi* appear to have been anticipated in the upper two lines.

In summary, 405 mean lunar months fall about one-ninth of a day short of 11,960 days, accumulating very close to a one-day shortfall in nine repetitions of the cycle, which amounts to nearly 295 years or, more exactly, to 299 chronological years (14.19.0.0). Compensation is attainable by advancing the base of the table by one day after the lapse of this span of time. Three items of circumstantial evidence suggest that the Maya astronomers may—at least once—have employed this stratagem, whether or not they were aware of the precise length of time that would necessitate a repeat

application. The table appears to represent the institutionalization of a new base, occasioned by the slow drift of the "zero" conjunction day.

The accumulation of shortfall in node positions proceeds at a more rapid pace than it does in lunations. Sixty-nine mean internodal intervals fall about 1.61 days short of 11,960 (again see last line of Table 3). In nine repetitions of the cycle the nodes therefore regress about fourteen and a half days, or close to half the effective length of an eclipse season for a tropical latitude. After this many repetitions, a locus in the table which at first predicted a maximally prenodal eclipse possibility, will now, on the ninth or tenth run of the table, predict one very close to a node; and by the eighteenth or nineteenth run of the table it will predict an eclipse possibility that is nearly maximally postnodal. Such loci in the table—which are the ones at the ends of the five-month intervals (just before the pictures) when the table is new—will be good as theoretically "eclipse-possible" times for about eighteen runs of the table. But those that mark nodal or near-nodal eclipse possibilities in the original table—especially such as those at the beginning of the table and after 88, 135, 223, and 358 months—will be good as predictors only for about nine runs of the table. And those that mark maximally postnodal eclipse possibilities—such as those just before the five-month intervals—will become obsolete after a single run of the table. Thus one envisions the possibility that the table may have been under more or less continual revision, perhaps every 33 years or so (the length of the table is about 32¾ years). If this were done systematically, and on the basis of adequate theory, then three or four of the five-month half-years would have to be moved one position to the left each time through. But if it were done haphazardly and pragmatically (as when an actually observed eclipse showed the table to be wrong), then some earlier "eclipse-possible" positions might survive their obsolescence for some number of runs through the cycle, thus distorting the structure of the table. An "adequate" theory, such as might have allowed the Maya astronomers to move the five-month periods systematically and with proper precision, would have required only that they had known the rate of regression of the node days, or of the eclipse seasons, through their sacred almanac. There is no clear evidence to indicate that they knew this, although the possibility cannot be excluded.

3. The Pictures. The "picture" breaks into the sequence of eclipse half-years, marking divisions of the cycle, have invited speculation as to their possible import. An early hypothesis, tested and rejected, was that they symbolized a series of solar eclipses that were actually observed by the Maya, and that they marked the dates of such eclipses.[16] Considering the structure of the table, however, this would seem, *a priori*, not a good hypothesis. The pictures follow positions in the cycle that are from middling to maximally prenodal. Their implied prenodal distances can be read from column 4 of Table 3, immediately above each of the nine horizontal dividing lines. These values, of course, are predicated on placement of the hypothetic nodes at the midpoints of the three eclipse seasons determined by the recorded almanac days, as previously explained. If the table is regarded as synchronic, then there is no room at all for juggling of the hypothetic node positions, for two of the three indicated eclipse seasons are represented as of about maximum possible duration, namely 35 days.[17] But if the table is assumed to contain anachronisms, including some already obsolete far-postnodal positions as a result of a "pragmatic" approach such as suggested above, then there is the possibility of moving the hypothetic nodes to positions a few days earlier than those determined above. But even with this provision, there is no way that the nodes can be placed sufficiently earlier in the table so that some of the "picture" positions will be postnodal. And if they were, the five-month periods would then be wrongly placed, and the table would lose up to 50 percent of its predictive potential. The pictures therefore cannot plausibly be assumed to have marked a series of actually observed eclipses. Such a series would have consisted solely of prenodal eclipses, most of them quite far or very far prenodal, which is most improbable as a sequence of empirical events. Yet the pictures are full of eclipse symbolism; and their placement exactly after the drops to negative maxima in the abnodal-distance function requires explanation.

It should be noted that to the extent that the pictures are consistently placed in relation to the ideal structure of such a table, as several of them are, they mark places where a partial eclipse of the sun might occur either on the indicated date or on a date one month later, or on both dates (somewhere on earth), with optimum conditions for a total eclipse of the moon at opposition time halfway between them. The Maya moon goddess hanging by her neck from a celestial band in the picture on codex page 53b is suggestive of such a reference. So also are some of the hieroglyphs in the legend over that

picture, the first three of which make reference to the "death" and the "darkening" of the "moon." And in the legend over the preceding column, which marks the end of a five-month eclipse half-year, there is a "solar eclipse" sign followed by the head of the sun god.

In a time-span of 32¾ years—the length of the table—about fifty lunar eclipses occur, and from any one location on earth about half of these are visible, namely those that happen during local nighttime. Of these, approximately a third are total eclipses. An eclipse table of this length constructed for lunar eclipses would have the same major divisions and subdivisions, but could not allow for as many lunar eclipse possibilities as there are solar. Not every half-year permits of one, nor does a half-year ever permit of more than one (there cannot be two, a month apart, as there can solar). They are variably spaced, most frequently at intervals of six months, but sometimes with intervals of eleven, twelve, seventeen, or twenty-three months. Yet the partitioning of the series into subdivisions of 47 and 41 months and the arrangement of these in the familiar pattern (47 + 47 + 41 for the 135-month division, another 47 + 41 completing the saros, and then repeating) are as for solar eclipses.

It may be helpful to be reminded of some of the differences between the conditions for a solar eclipse and those for a lunar eclipse. A partial solar eclipse occurs when the sun enters the moon's penumbra, and a central eclipse (total or annular) when it enters the umbra or the inverted projection of the umbra beyond its vertex. Because the ratios of the diameters of the sun and the moon to their respective distances from the earth are approximately equal (varying in relation to each other slightly due to orbital eccentricities) the vertex of the moon's umbra comes close to the earth's surface during an eclipse syzygy, falling just short of it during an annular eclipse, and just reaching it or penetrating it (geometrically speaking) to a slight depth during a total eclipse, thus describing in either case a narrow path of centrality on a portion of the face of the earth, but never engulfing the earth. A visible lunar eclipse on the other hand, whether total or partial, requires entry of the moon, totally or partially, into the earth's umbral cone. Entry into the penumbra does not suffice, because the unshadowed portion of the sun (in what would be seen by an observer on the moon as a partial terrestrial eclipse of the sun) is sufficient—because of the sun's intensity—for full illumination of the moon while it is in the earth's penumbra. Thus, although the earth casts a larger shadow into space than does the moon, the ecliptic limits for a visible lunar eclipse are narrower than those for a solar eclipse, and lunar eclipses are correspondingly rarer (as a phenomenon for the earth as a whole, although of course not for a single point of observation). The pertinent fact for present purposes is that lunar eclipses therefore, because of their shorter eclipse seasons but yet more frequent opportunities for verification at a single location, offer more clues and a somewhat better guide to the construction of a primitive solar-eclipse table than do the solar eclipses themselves. (A stationary observer has a 50 percent chance of verifying a lunar eclipse, whereas with solar eclipses it is closer to about 8 percent.)

Referring now to Table 3, it is seen that the horizontal dividing lines (which correspond to the picture dividers in the Maya table) immediately follow the greatest negative values in the abnodal distance function, these being where they are because of the shortening of the immediately preceding eclipse half-years from six to five months. By adding half a lunar month to these, one finds minimal abnodal distances for oppositions, and hence the most favorable times for total lunar eclipses. It is almost necessary to conclude that these facts played some role in the placement of the five-month periods in the layout of the Maya table, and that the pictures relate to this. One is led to suspect for a given recension of the table, when some or all of the five-month periods required relocation, that their placement may have been governed to some extent by the record of recent lunar observations together with a rule that a total eclipse of the moon, or the first in a single series of such, should be preceded by a five-month eclipse half-year. In this case, the circumstances of observability of total lunar eclipses—whether nighttime or daytime locally—would result in departures from the "ideal" pattern of lengths of the subdivisions of the eclipse cycle. Missing the first two of such a series (consisting usually of three or four at six-month intervals) would transform the normal pattern of Table 3*a* into the Maya pattern as in Tables 2 and 3*b* and Figure 3. A pattern emerging from such a series of observations might well have been made canonical and turned into a formula for prediction into the future, or for warning of possibilities that have precedent. There is reason to believe that the glyphic annotations at the heads of the 69 columns of the Maya table, and over the pictures, may be a log of precedents, or a conflation of several such. As a final point in this argument it may be noted that at several of the divisions in the table, in the

pictures or in the legends over them, there are references to both an eclipse of the sun and an eclipse of the moon. In five cases there are paired eclipse symbols, the first solar and the second lunar. A sixth case, represented differently, has already been noted. These appear to be an explicit acknowledgment of the fact that a lunar eclipse close to a node may be preceded by a solar eclipse (partial) half a month earlier, which then is more or less maximally prenodal and entails shortening the preceding half-year to five months.

There is still the matter of the tenth or "extra" picture to dispose of. A table of this length can have only nine natural subdivisions (it is one 41-month subdivision short of two saroi). The first nine of the picture breaks initiate eclipse seasons, coming after five-month half-years, and at positions that are more or less maximally prenodal. The tenth picture, however, as noted earlier, comes in the middle of an eclipse season, after a six-month half-year, and at or very close to a node. Yet it has a prominent display of the paired eclipse symbols, solar and lunar like the others, both in the picture and in the glyphic legend above it. This shows it to be an anachronism, for there cannot be a lunar eclipse either at this time (it is conjunction) or half a month later as in the other cases (in this case it would be several days past the lunar ecliptic limit and is in one of the longer periods when a lunar eclipse is excluded). The tenth picture, then, must be seen as a retention from an earlier version of the table, one in which a *12 Lamat* conjunction was approximately fifteen days prenodal rather than at a node as in the present version. Its current function must be that of a historical marker, memorializing the date and circumstance of the institution of *12 Lamat* as a canonical base for eclipse cycles.

4. The Maya Computations. The Maya numerals and their Arabic equivalents in Table 2, column 5, are the distances from the *13 Muluc* base of the codex table to the successive almanac days named in the lowest of the three lines of these in the same table. To be compared with these values are the numbers with decimal fractions in Table 3, column 5, which are the intervals from a hypothetic zero point (positing coincidence of a lunisolar conjunction with a node passage) to the ends of successive six-month or five-month eclipse half-years grouped as these are in the table of the codex (Figure 3). The numbers of the first of these sets are whole integers, the results of computations by Maya primitive astronomers, employing whatever methods they had at their disposal for reckoning lunations and conjunction days, and without benefit—so far as we know—of fractional arithmetic. The second set consists of multiples of the number 29.530588 computed on a modern handy calculator and rounded off to two decimal places. Had they been rounded off to the nearest integer in each case, they would have been in near-perfect agreement with the Maya values. Of the 69 Maya values, 54 are exactly those that would be obtained from our experimental table by rounding off the values in this way, following the usual conventions. Of the other fifteen Maya numbers, eleven differ from the rounded-off experimental figures by -1, and four by $+1$; but the actual fractional differences are mostly small, averaging only 0.17 of a day in their deviation from the dividing line between fractions dropped and fractions counted as wholes in the rounding-off process. It is worth noting that the four instances of $+1$ deviations in the Maya integers would vanish if we took as our primary evidence the cumulative totals as written in the codex rather than the almanac days recorded there. However, had that policy been followed throughout, it would have introduced 35 additional -1 deviations and increased nine others from -1 to -2. The string of -1 errors in the cumulative totals beginning on codex page 57a and continuing to the end of the table on 58b can be attributed to a single error in that amount that went uncorrected, and so was carried forward to the end of the table. An alternative hypothesis, sometimes entertained, is that the "error" was deliberate, signaling an intended shift from the lower line of almanac days to the middle line, thus shortening this run of the cycle to 11,958 days as written, for a correction in the amount of two days. Yet another current hypothesis is that the cumulative totals were not intended to be in complete agreement with any single line of almanac days, the one series being empirical and the other theoretical—but with three choices each time to allow for plus or minus deviations in the amount of one day. The description given above, however, has followed the hypothesis that a single line was the intended referent throughout, that the one-day shortening of the cycle embodies a rule for its use every ninth time, or when perceived as necessary, and that these are consequently the occasions for shifting from one line of almanac days to the line above. It is the aforementioned relation between the *13 Muluc* date 9.12.10.16.9 and the *12 Lamat* date 9.16.4.10.8, as well as the fact that each line of almanac days in the table exhibits the one-day foreshortening, that has prompted this choice from among the available hypotheses. There is evidence, however, as

will be seen later, of the employment of another and more drastic foreshortening device – somewhat similar in principle to that employed with the Venus table – that would make possible the holding of epochal conjunction days to any given day in the almanac, say *12 Lamat*. But whether held, or allowed to slip a day every nine cycles, there is no way of containing such an epochal almanac day, or series of adjacent ones, within eclipse seasons for longer than eighteen or twenty cycles. To this end, the slipping procedure does slightly better. In either case, the span of time is in the neighborhood of six centuries.

5. The Distribution of 30-Day and 29-Day Months. A simple alternation of 30-day and 29-day months in a lunar calendar yields a mean lunar month of 29.5 days, causing the pace of the calendar to exceed that of its object. Since the Maya eclipse table spans 405 moons, such an unmodified alternation would cause it to fall twelve and a half days short of its proper length: $11{,}960 - (405 \times 29.5) = 12.5$. Additional days are required to compensate for the shortfall. This in effect means that the ratio of 30-day to 29-day months, and the pattern of their alternation, must be modified. Permitting two consecutive 30-day months, and shifting the ordinal positions of each of the two varieties of months from odd to even and even to odd, effects a half-day compensatory increment. If this method were employed throughout the table, twenty-five modifications would be required. An alternative, substituting a 30-day month for a single 29-day month, without changing the ordinal positions of the others, and thus permitting a sequence of three consecutive 30-day months, effects a whole-day compensatory increment. The method employed in the Maya eclipse table is transparent. There are nine 5-month eclipse half-years, of 148 days each, distributed among sixty of the 6-month half-years. Each of the 5-month periods has three months of 30 days to two of 29 days. By its change of the ratio, each such period automatically contributes a half-day compensatory increment, for a total of 4½ days. This leaves eight to be provided by other means in a full run of the cycle, or seven in this special 11,959-day truncated run. Among the sixty 6-month periods, fifty-three are of 177 days each $[(3 \times 30) + (3 \times 29)]$, but seven are of 178 days $[(4 \times 30) + (2 \times 29)]$. (These are marked † in column 7 of Table 2. Only one of them is so indicated in the series of intervals in the codex table, Figure 3, bottom pair of lines. Their determination is from the series of almanac days.) Each of these 178-day periods provides one whole-day compensation, which could be made either at once (for example, $30 + 29 + 30 + 30 + 30 + 29$) or in two half-day increments (for example, $30 + 30 + 29 + 30 + 30 + 29$). An error graph, which can be constructed from the differences between the integral values and the fractional values of columns 6 and 5 of Table 3, confirms that there are nine half-day and seven whole-day compensations. Had the eighth whole-day intercalation been included, the second-last half-year would be of 178 days, and the normal length of the cycle, 11,960 days, would be attained. As has been seen, the end result of the Maya computations is remarkably close to what they would have had if we had done the figuring for them.

6. The Preface to the Maya Eclipse Table. Pages 51a–52a of the table contain prefatory matters that raise more questions than can be answered. The content may be summarized as follows (labeling the five columns on page 51a as *A* to *E*, and the six on page 52a as *F* to *K*).

Column A (· · ·, *4 Ahau, 8 Cumhu, 12 Lamat*, 8 days · · ·, 9.16.4.10.0 [black number], 10.19.6.1.8 [red number], *12 Lamat*). The glyph at the top of the column is obliterated. *4 Ahau 8 Cumhu* refers to the zero day of the Maya day count. *12 Lamat*, as indicated by the following "8 days · · ·" notation, refers to the eighth day after the zero of the day count, which is at that position in the almanac. This serves as a special base from which to reckon the following interval or intervals (see "Numerology" for analogy with "ring number" bases). The black distance number is written in the codex as 8.16.4.10.0, which does not accommodate the terminal day *12 Lamat* written below it. The initial "8" can only be a copyist's error for 9, and is so corrected. The number 9.16.4.10.0, an integral multiple of the length of the almanac ($5{,}434 \times 260$), added to the special base, reaches the date 9.16.4.10.8, which is on a day *12 Lamat* (*1 Muan*). This date recurs in column *K*. The interscribed red number 10.19.6.1.8, applied to *4 Ahau 8 Cumhu*, specifies the date with that number in the day count, which is also a day *12 Lamat* (*6 Cumhu*). Its distance from the special base is again a multiple of the almanac ($6{,}073 \times 260$). The interval between these two *12 Lamat* dates is 1.3.1.9.0, or 166,140 days, or 14 eclipse cycles less five almanacs (1,300 days). It is equal to 5,626 lunations (of 29.530588 days) plus the 0.91 part of a day, or to 5,626 Maya moons (of 29.530864 days) minus the 0.64 part of a day. It is not a multiple of the internodal interval however, or close to one (it is about 64 days short of such a multiple), so that if one of the two dates was within ecliptic limits, the other was not.

Columns B–H. Below the glyphic annotations at the top, which are mostly obliterated, these seven columns contain thirteen numbers, ten of which are multiples of the length of the eclipse cycle (1.13.4.0, or 11,960 days) and the other three of which are equal to multiples of that number with increments that one is perhaps obliged to suppose intentional and somehow significant, but some of which may nonetheless have been due to errors in compilation. It will suffice to note that the list contains the following values, although not in this order:

1.18. 5.0, = 1 EC + 5.1.0 (1,820 days,
3. 6. 8.0, = 2 EC or 7 almanacs)
4.19.12.0, = 3 EC (entered twice)
6.12.16.0, = 4 EC (entered twice)
8. 6. 2.0, = 5 EC
9.19.12.0, = 6 EC + 6.0 (120 days)
1. 6.11.10.0, = 16 EC
1. 8. 4.14.0, = 17 EC
1. 9.18. 0.0, = 18 EC
2.11.10.11.0, = 31 EC + 13.0 (260 days,
3. 4.15.12.0, = 39 EC or one almanac)

Below the numerals are the almanac days *12 Lamat, 1 Akbal, 3 Etznab, 5 Eb*, and *7 Lamat*. These are separated from each other in the almanac by 15-day intervals, increasing in the order of listing, for a total of 60 days. They are repeated, identically, in each of the seven columns.

Column I (· · ·, 8 days, 1 *uinal* and 5 *tuns*, 2 · · ·, thirteen 13's). The uppermost glyph is mostly obliterated, but a surviving detail (detectable only in the photographically based editions of the codex) appears to narrow down the choice to either the moon sign or the death sign. The "8 days" recalls the similar entry in column *A*, and is assumed thus to refer to the special *12 Lamat* base, eight days after the start of the day count. The "1 *uinal* and 5 *tuns*" are the period 5.1.0, or 1,820 days. This period, equal to seven times the 260-day almanac and to five times the 364-day computing year, was apparently one of the much used Maya reckoning units. It is the subject of four different multiplication tables in the Dresden Codex and of one in the Paris Codex, and it is a factor in five of the numerologically contrived long-reckoning numbers that are applied to "ring" bases in the Dresden Codex. It recalls the discrepancy between what is expected (1.13.4.0) and what is written (1.18.5.0) in the table of multiples in columns *B–H*. But the next glyph and the thirteen 13's following the "1 *uinal* and 5 *tuns*" suggest yet another possible significance. It can be seen in Figure 3 that this glyph (column *I*, fourth glyph), except for its numerical prefix "2," is the same as that following the "8 days" in the fifth position of column *A*. Whatever its inherent meaning may be, its function there could be seen as that of marking a quantity to be added to what precedes the statement of that quantity. The prefix "2" which accompanies it in column *I* might then be interpretable as an indicator of a double addition, which, if taken together with the thirteen 13's that follow, produces the number 10.10.9 (= 3,809 days). This is one of the good solar eclipse intervals, as can be seen in the last column of codex page 56a, or in Tables 2 and 3. There are thus two alternative possibilities of relevance here for the "1 *uinal* and 5 *tuns*," but as yet no other suspected significance for the thirteen 13's.

Columns J–K. Four dates are recorded here, reckoned from the normal base of the day count, *4 Ahau 8 Cumhu*, which is recorded at the head of each column. There are two copying errors, an "8" for 18, and a "10" for 11. These are corrected (with prefixed asterisks) in the following transcription. From earliest to latest they are:

K-black: 9.16.4.10.8, *12 Lamat* (*1 Muan*)
K-red: 9.16.4.11.3, *1 Akbal* (*16 Muan*)
J-black: 9.16.4.*11.18, *3 Etznab* (*11 Pax*)
J-red: 9.19.*18.7.8, *7 Lamat* (*16 Zac*)

The first one is the date determined also in column *A*. The first three are at 15-day intervals, as are the corresponding almanac days in columns *B–H*. That series proceeds by two further 15-day intervals, to *7 Lamat*. If the series of dates here did also, it would reach 9.16.4.13.8, *7 Lamat* (*1 Cumhu*). Instead, a date 26,520 days later is indicated. This interval, less one day, is an approximate eclipse interval (898 moons plus about half a day, and 153 mean internodal intervals plus about 2½ days) and is also the interval between the *13 Muluc* date of previous reference and the *12 Lamat* date, 9.16.4.10.8. However, if either or both of the *13 Muluc* and *12 Lamat* dates were eclipse dates, then neither of the *7 Lamat* dates can be; although all four are possible conjunction dates.

These dates have invited attempts to place the eclipse table in Maya chronology. It has been proposed that the first three, which are at 15-day intervals, may be the dates of two solar eclipses a month apart and of a lunar eclipse between them; that a node must therefore have been close to the *1 Akbal* date, and that the *12 Lamat* date, 9.16.4.10.8, must then have been approximately 15 days prenodal; and that since the *12 Lamat* at the end of the eclipse table is obviously at or very close to nodal position,

it cannot possibly be the one of the date 9.16.4.10.8, but must be one of about nine or ten eclipse cycles later, say 10.11.3.10.8 or 10.12.16.14.8, by which time the node would have migrated to a position about 15 or 16 days earlier in the cycle and in the almanac ($9 \times 1.61 = 14.49$ days; $10 \times 1.61 = 16.1$ days).[18] The conclusion follows correctly, and is therefore at least as good as the premise. In regard to this, however, it needs to be remembered that two solar eclipses a month apart cannot have been visible from the same region of the earth, so it is not possible for the two hypothetic solar eclipse dates to have been based on Maya observations. At least one of them has to have been a prediction, in line with their knowledge about the possibilities either side of a total lunar eclipse. The safest part of the premise, then, is the supposition of a lunar eclipse, perhaps total, on the date 9.16.4.11.3, *1 Akbal* (*16 Muan*). Embarrassing for the hypothesis, and for the conclusion that follows from it, is the presence of the seven times repeated sequence of these same almanac days *and two more—also at 15-day intervals*—in the adjacent columns *B* to *H*. (Three solar eclipses at 30-day intervals are, of course, impossible, as are two lunar eclipses a month apart.) Favoring the hypothesis, however, is at least one very plausible eclipse date from an inscription, and two other quite plausible ones, that are so distributed as to be optimally placed in relation to nodes if the *1 Akbal* date of this passage in the codex is also at a node. These would make the *12 Lamat* date the more likely candidate for the predicted but unobserved one of the pair of supposed solar eclipse dates, which would be in conformity with the hypothesis about how lunar eclipses were employed as guides to the placement of the five-month periods in the eclipse-warning table. All of this is also concordant with the earlier conclusion concerning the anachronism of the tenth picture in the table. It must be of the epoch of 9.16.4.10.8, while the others are of the current epoch, some nine or ten eclipse cycles later.

The purpose of the series of five almanac days, repeated under each column of multiples of the eclipse cycle, remains open to conjecture. There is the possibility of a double relevance for the 15-day intervals. On the one hand they are approximations to the intervals from conjunction to opposition and again to conjunction, so that any three of the almanac days could represent a set of hypothetic eclipse possibilities, solar and lunar; and, on the other hand, they approximate the distance that the nodes migrate in the length of time that it takes for conjunctions to migrate one full day in the same cycle, namely in about nine repetitions. Any subset of three out of the five almanac days, then, taken in order from top to bottom, could represent the epochal eclipse possibilities for one given run of the cycle, while successive such sets, moving from bottom to top, could represent the node migrations corresponding to the lengths of time that require one-day corrections (or equivalent adjustments, see below) in the calendrical reckoning of lunations. If this second potentiality was a factor in its determination, then the significance of the recorded *7 Lamat* date can only have been commemorative or something extraneous to the reckoning of eclipses.

7. The One-Day Corrections. As noted earlier, the discrepancy between 405 lunations and 46 almanacs (the length of the Maya eclipse cycle) is about $^{11}/_{100}$ of a day, so that approximately every ninth run through the cycle would call for a one-day adjustment in the locations of conjunction days in the almanac. In one interpretation, this is the function of the three lines of almanac days in the table proper, a shift from a lower to the next higher line accomplishing a one-day compensation for the accumulated shortfall of lunation times in nine or so runs of the table. If this was their intended function, and if the length of the eclipse seasons was properly appraised, then there should be just three such lines, allowing for two shifts. During this time a given series of adjacent epochal days—such as the three in the sixty-ninth column of the table—would have passed from an initial maximum prenodal position, to a nodal position, to a maximum postnodal position, after which its relevance is past. Then a new epochal series would need to be located and instituted, which would require a more drastic abridgment of the final cycle of a series. There is circumstantial evidence suggesting that such a procedure was indeed in effect, and that, employed more often, it provided a way even to dispense with the one-day shifts in the almanac positions of the epochal day.

This possibility rests on the felicitous circumstance that ten lengths of the almanac amount to a little over a day more than a good eclipse interval. If this amount is subtracted from an eclipse cycle, then the remainder is a little over one day *less* than another good eclipse interval. Such a foreshortened cycle can therefore be employed periodically, in place of a full cycle, to effect a compensation for accumulated shortfall in lunation times, while still preserving the same almanac day—say *12 Lamat*—for the beginning and the end of the cycle. The optimum ratio is ten full cycles of 1.13.4.0 or 11,960

days each, to one short cycle of 1.6.0.0 or 9,360 days. It has a remarkable accuracy, both in holding epochal lunation days to a fixed place in the almanac, and in reckoning lunar phenomena over long periods of time. It allots 4,367 lunations to a period of 17.18.4.0 or 128,960 days, which is equivalent to a mean lunar month of 29.530570 days. This is an improvement over the Maya "first approximation," as in the single eclipse cycle, which is equivalent to a mean lunar month of 29.530864 days; and it may be compared with our modern figure of 29.530588 days.

The conclusion that the Maya astronomers and calendar priests had discovered the possibility of this manner of correction, and even the optimum ratio of full to abridged cycles, rests perhaps a bit precariously on a few pieces of circumstantial evidence. One such piece consists in a pair of dates, recorded in the "ring number" and "serpent number" manners, that are separated by exactly twice this interval, as if there had been two successive applications of the formula.

10. 7. 4. 3. 5, *3 Chicchan 13 Yaxkin*
− 8.11. 7.13. 5, *3 Chicchan 8 Kankin*
= 1.15.16. 8. 0, = 2 × (17.18.4.0),
= 2 × (128,960 days).

Both of the dates have the same position in the almanac, *3 Chicchan*. Both have a moon age, reckoned from conjunction, of between three and four days, which is an amount by which recorded moon ages in inscriptions at many Maya sites fall short of true moon ages, because of their being reckoned from the first appearance—or "birth"—of the new crescent moon, rather than from estimated conjunction days (as at certain other sites). A part of the significance of the dates therefore can be ascribed to their being dates of the rebirth of the moon. In the case of the later one, this appears to be borne out by the "celestial birth" symbolism of the open jaws of the serpent, by the rabbit form assumed by the emerged deity (the rabbit is a moon symbol in Mexican iconography and in postclassic Mayan), and by the presence of a "birth" hieroglyph in the accompanying brief text. Also in the case of the later date it can be shown (1) that eighteen days earlier was the date of a lunar eclipse (on the assumption that the *1 Akbal* date of the preface to the eclipse table was a node day, or very close to one), and (2) that three days earlier was potentially a date for a solar eclipse (predicted, surely, if not actually observed); so that the *3 Chicchan* date was that of a rebirth of the moon under somewhat special circumstances. Whatever else of astronomical phenomena may have lent special significance to either or both of these dates is unknown.

The *3 Chicchan* dates can have only one place in the eclipse cycle: some three days after the completion of 335 lunations, or four days after the *12 Imix* in the Maya table (Table 2, following node 57; Table 3, line 57; Figure 3, page 55b, second-last column; note that the theoretical figure, 9,892.75, would have called for one more day here, 9,893 rather than 9,892, or *13 Ik* rather than *12 Imix*). This makes it possible to specify the corresponding epochal dates, which of course have the same interval between them. It is of interest that the later of these is separated from the presumed date of the institution of *12 Lamat*, 9.16.4.10.8, by an interval that is equal to five full eclipse cycles plus one short one. This, although apparently involving a different ratio, is more likely an instance of the same. It is what would be expected if the corrective short cycle were placed in the middle of the ten full cycles rather than at the end; that is, if the error were corrected when it reached a magnitude of a little over half a day, substituting smaller errors, positive and negative, for an otherwise larger range of errors, only positive.

10. 7. 4. 3. 5, *3 Chicchan 13 Yaxkin* (*b.* ☽)
−4 interval, conj. to cresc.
10. 7. 4. 3. 1, *12 Imix 9 Yaxkin* (conj.)
−1. 7. 8.13 = 335 lunations
10. 5.16.12. 8, *12 Lamat 11 Tzec* (epoch)
− 9.16. 4.10. 8, *12 Lamat 1 Muan* (epoch)
9.12. 2. 0 interval between epochs
−8. 6. 2. 0 = 5 full eclipse cycles
1. 6. 0. 0 = 1 short cycle,
= 9,360 days, or 36 almanacs.

The difference between the length of the full cycle and that of the short cycle, namely 10 almanacs, is equivalent approximately to 88 lunations and to 15 internodal intervals; 10 and 88 are even numbers, 15 is odd. Therefore, in reckonings concerned with lunations but where eclipse syzygies are not at issue, the corrective foreshortening can be halved and applied more frequently, permitting a yet closer adherence of the timing of ordinary lunar phenomena to a schedule of almanac days.[19] There are a few pairs of dates in the Dresden Codex that seem to imply such an application. Without intermediate dates it is not possible to distinguish between two applications of a 5-almanac foreshortening and one application of a 10-almanac foreshortening. Such an intermediate date is that of 9.17.8.8.5, *3 Chicchan 18 Xul*. It has the same almanac position and the same moon age (to within

1/100 of a day) as does the later one of the two dates discussed in the preceding paragraph; and like that one, this too is given in the "serpent number" manner. It may be assumed that there was yet some other astronomical significance, besides its moon age, for this date; for over the jaws of the serpent in this case is the Maya rain god (celestial identification unknown). The interval between these two dates is equal to 6 eclipse cycles less 5 almanacs, or 5 eclipse cycles plus 10,660 days.

10. 7. 4. 3. 5, *3 Chicchan 13 Yaxkin*
− 9.17. 8. 8. 5, *3 Chicchan 18 Xul*
9.15.13. 0, = 5 × (1.13.4.0) + 1.9.11.0,
= 5 × (11,960) + 10,660 days.

The problem for the Maya astronomers was not simply that of determining the natural cycles of celestial phenomena but, equally important, that of integrating these with the cycle of days in the sacred almanac. This second desideratum required an ideal cycle—for lunar reckoning as for Venus reckoning—that was a multiple of the almanac. The almanac was peculiarly well suited for the definition of eclipse seasons and for the isolation of their nodal midpoints, as it was also for the delimitation of the 135-lunation divisions. And in its fifth and tenth multiples the almanac also offered a peculiarly fortunate opportunity, apparently grasped by the Maya, for refining this reckoning instrument to one of great precision. But the primacy of the almanac seems to have placed an impediment in the way of discovery of the special significance of the saros. The saros is there, as it has to be, but only as one out of sixty-nine specified eclipse possibilities. Its nonrecognition makes for some eventual awkwardness in the major groupings of lunar half-years: the sequence of divisions, of 135+135+135, and so forth, is forced; the more natural one would have been 135+88+135+88, and so forth, where the 135's are optimally 47+47+41, and the 88's are 47+41. But to have integrated this arrangement with the almanac into a single repeating scheme would not have been possible, except in a scheme of undue length. Similarly, the Metonic cycle appears to have attracted no particular attention, It too is there, as it has to be (at 235 lunations), but again only as one of many eclipse possibilities. Any concern for the tropical year was subordinate to that for the almanac.

VI. NUMEROLOGY

The prime use of Maya astronomy was to learn the habits of the celestial powers so as to make predictable the hazards of living under their influence. Keeping track of the schedules of the heavenly bodies, and predicting their appearances, disappearances, and crises, depended on the auxiliary calendrical and numerical sciences. In its discovery of regularities in phenomena, and in its descriptive formulations of these, Maya calendrical astronomy was akin to science (in a kind of ancestral relationship); but in its interpretative edifice, and in its applications, it pertained rather to the domains of astrology, demonology, and divination. The predictions that it made possible must at times have seemed awesome. It appears that rulers and their priesthood found uses for this highest form of divination. One of them was to forewarn against dangers emanating from the celestial scene, so that preventive measures might be taken—rituals, offerings, and sacrifices directed to the appropriate deities. Another was to gain the most auspicious times and circumstances for projected undertakings. Both of these were in application to matters of the more or less immediate future. But another was to the fixing of events in very distant times, past and future, providing mythological and numerological charter for the positions of rulers, and seemingly forecasting their continued existence and influence in afterlife.

In the section "Calendar, Chronology, and Computations," above, there was brief reference to a passage from an inscribed text at the site of Palenque that documents the accession, to at least titular rulership, by the boy Pacal at an age of approximately 12⅓ years. Although introduced there only as a computational problem, it also illustrated one of the seemingly fanciful uses to which the labors of the court arithmeticians and calendar keepers were put. There are several of these, from several sites—Tikal, Quirigua, Copan, Yaxchilan, Palenque, and others. They relate events in the lives of rulers to similar events in the careers of mythological ancestors and gods of the far distant past, or to anniversaries, as it were, of these events in the distant future when these rulers too shall presumably have become gods. This was one type of royal numerology. There was a second, which operated with numbers of much more modest magnitudes, covering spans of time that were either contained within the current chronological era or that extended only minor intervals beyond its beginning. In one respect these are the more interesting, because it is possible to discern in some of them a motive—other than the attainment of sheer magnitude—for their being the particular numbers that they are. A few examples of each category will be

cited here, all from Palenque, together with relevant portions of their immediate contexts, which illustrate something of the quality of the Mayan concern with numbers and days.

The accession of Pacal is documented in at least eight locations in the hieroglyphic texts of Palenque, so that its date and the age of the boy on that occasion are well secured. One of them, from the east panel of the Temple of the Inscriptions, states that the accession was 17.13.12 before the period-ending *1 Ahau 8 Kayab* (which is 9.10.0.0.0), this chronological anchor then being made further explicit, redundantly so, by stating that it was the end of the tenth *katun* and the midpoint of the current *baktun*. The indicated arithmetic fixes the accession date at *5 Lamat 1 Mol* (9.9.2.4.8). A passage from the west panel in the same temple, to which reference was made earlier, has it that it was 12.9.8 from the day of his birth, *8 Ahau 13 Pop*, to the day of his accession, *5 Lamat 1 Mol*. Then it explains further that this latter day was 2.4.8 after the *3 Ahau 3 Zotz* period-ending (the *katun*-ending 9.9.0.0.0). This doubly confirms the information derived from the passage in the east panel, and further, and redundantly, fixes his birth date of *8 Ahau 13 Pop* at 9.8.9.13.0—which fact is known also from other texts, including an initial series that displays the same day number with head-variant numerals. Thus far the text is sober history. But it continues from there with the statement that it was 7.18.2.9.2.12.1 from the assumption of rulership by an ancient deity or celestial forebear, on a day *1 Manik 10 Tzec*, to the identical event on the part of the young Lord Pacal of Palenque on *5 Lamat 1 Mol* (9.9.2.4.8). And it goes on further to state that it will be 10.11.10.5.8 from the birth of Pacal (which was on *8 Ahau 13 Pop*, 9.8.9.13.0) to yet another *5 Lamat 1 Mol*, and that this *5 Lamat 1 Mol* will be just eight days after the completion of one *pictun* (1.0.0.0.0.0) in the current day count.

The passage is of interest for its projections into the past and into the future, and also for its structural parallelisms. The appeal to the past event, of identical kind, not only equates the status assumed by the young heir to the throne, on the historical date 9.9.2.4.8, with that assumed by this deity in a far past era, but appears to go beyond that, to draw a special parallel, or to assert a special likeness, between these two accessions, the secret of which is perhaps locked in the meaning of the great distance number. The reference to the future event is of a different sort. Here the parallelism is between two pairs of dates, the earlier one in each pair being the same, namely, *8 Ahau 13 Pop* (9.8.9.13.0), the day of Pacal's birth, and the later one in each pair having the same position in the calendar round, *5 Lamat 1 Mol*, the calendar day of Pacal's accession, but the one of the second pair being the eightieth calendar-round anniversary of the one in the first pair (4,160 years later), and being moreover the first *Lamat* (just eight days) after the end of one *pictun*, that is, after 8,000 chronological years counting from the beginning of the current era. It must be supposed that, to have a point made of it, something auspicious must have been seen in that coincidence.

Another great distance number, 5.18.4.7.8.13.18, mediates between a *9 Ik 10 Mol* date and a contemporary date of *9 Ahau 3 Kankin* (9.11.1.2.0) in the inscription of Temple XIV at Palenque, but the hieroglyphs naming the events for these two dates are not yet understood. The human protagonist of the contemporary date is Chan-Bahlum, the son and successor of Pacal. The others are gods.

The motivations for the particular values of these great distance numbers are not clear. The one in the Temple of the Inscriptions is equal to 455,393,761 days, or 1,247,654 calendar years plus a remainder of 51 days. That of Temple XIV is 340,469,558 days, or 932,793 calendar years and 113 days. Projections that far into the past, pending any better hypotheses, are assumed to have been intended to reach dates of cosmic importance and to represent the results of calculations into the past, perhaps involving several astronomical variables. The events ascribed to such dates, where their glyphs are understandable, are "accessions" of deities who rose to power in eras past. The current era was about halfway into its tenth *baktun* at that time (about 3,800 years), and the preceding era had had only thirteen *baktuns* all told (about 5,125 years); so the ages of the past must have been envisioned either as having spanned a great many more eras of comparable lengths, or else a lesser number of eras of much longer durations.

As numbers, more instructive are those of the more modest projections that go back merely to the beginnings of things pertaining to the present era. These allow us a glimpse into numerology at work, and in some cases, of myth in the making. Mention has already been made (in the section "The Venus Calendar") of those five-place numerals in the Dresden Codex that on the surface appear like any other numerals of comparable magnitudes fixing dates in the day count of the current era, but which, unlike ordinary Maya day numbers, are not reckoned from *4 Ahau 8 Cumhu* (the start of the era and normal zero of the count) but are

reckoned instead from various special bases or epochal days at relatively short intervals prior to the beginning of the era. The intervals from day zero back to these negative bases—each base unique to the historical date that is reckoned from it—are given by the so-called ring numbers. Those leading forward from the pre-zero bases to the respective historical dates will here be called "ring-based day numbers," in order to distinguish them from the normally based variety. One of these was encountered in the prefatory page to the Venus tables (Dresden Codex, page 24). In that example the ring-based day number was 9.9.16.0.0, and the special ring-number base was at −6.2.0, which is equivalent to the date of 12.19.13.16.0 in the preceding chronological era. If we subtract 6.2.0 from 9.9.16.0.0, or if we add 9.9.16.0.0 to 12.19.13.16.0 and cast off 13 *baktuns*, we arrive at the date in the current era that is determined by this device, 9.9.9.16.0 in the normally based day count. (In verifying this, it should not be forgotten that a unit in third place of a day-count numeral is equal to eighteen units in the second place, whereas in all other places the ratio is one to twenty.)

Why the roundabout way of specifying a date in the current era? The answer has already been anticipated above in the discussion of the Venus example. The numbers that tell the days from the pre-zero "ring" bases to the related historical dates are contrived numbers—contrived in such a way as to provide, for each historical date, a base which is its like-in-kind in respect to its position in one or more pertinent calendrical or astronomical cycles. The day of the special base thus has significant attributes in common with the historical day whose chronological position is reckoned from it; and it is, moreover, the *last possible one* to do so before the beginning of the current era. The difference in quality between the two categories of day numbers, the ring-based and the normally based, can usually be seen when those which are associated with a single date are reduced to their prime factors. As a category, the ring-based ones are composite to a degree and in a manner that would not be expected by chance, whereas the category of normally based day numbers are in respect to their composition as if chosen at random from within the same general range of magnitudes (roughly from 1,200,000 to 1,600,000). Those of the one set are contrived; those of the other just "happened." There are fifteen ring-based day numbers in the Dresden Codex (eighteen examples, but with three repetitions). Eleven of them are multiples of the almanac, and four of these are also multiples of the triple almanac (one suspects an interest in Mars, with mean synodic period very nearly 780 days). Other periods which are contained integrally in one or more of these numbers are the computing year of 364 days (in five of them), the five-Venus-year or eight-calendar-year cycle of 2,920 days (in the example in the section "The Venus Calendar"), the 81-moon period of 2,392 days corresponding to the Palenque moon ratio, and in two instances a factor of 9 that may perhaps relate to the Lords of the Night and the glyph *G* cycle. A few of the ring-based day numbers are integral multiples of only one of these basic periods (the almanac is the most frequent), but others are multiples of two, three, or four of them. The ring-number bases, except for one of them, are at intervals ranging from 17 to 2,200 days prior to the beginning of the era. The exception is at 51,419 days (7.2.14.19) before the era; and the ring-based day numbers (two of them in this instance, interscribed red and black) that are reckoned from this anomalous base are exceptional in that they do not contain the more usual clusters of factors. One from this pair contains a prime factor of 59,167. Unless a component of such magnitude were of interest in the computation, there would be no apparent reason for having such a large ring number.

The events that are ascribed to the various historical dates reached by these contrived counts in the Dresden Codex are not known, because the meanings of crucial hieroglyphs are still elusive. But there are analogs to these, and kindred manners of reckoning, in at least a few of the monumental inscriptions of the classic period; and although the historical dates in these cases are of events in human history—in contrast to the presumably astronomical events of the Dresden Codex—similar ends are served by the numerological contrivances. They establish likeness of kind: between the dates, between the events, and here apparently also between the protagonists.[20]

The initial date of the Temple of the Cross at Palenque is 12.19.13.4.0, *8 Ahau 18 Tzec*. This is a date in the previous chronological era, at a distance of 6.14.0 before its end and before the beginning of the current era; it is thus equivalent to a ring-number date of −6.14.0. Considering that in the majority of instances of reckonings from such bases (that is in eleven out of the fifteen in the Dresden Codex) the base date and the historical date share the same position in the almanac, one would test for that possibility here. Since the base date is an *8 Ahau*, another *8 Ahau* date is sought that would be in historical time at Palenque. There

is one, but in this instance it is not found in the same inscription. It is the *8 Ahau 13 Pop* of Pacal's birth, 9.8.9.13.0, recorded in several other locations, two of which have been cited above. The interval from a day 6.14.0 before zero to one that is 9.8.9.13.0 after zero is equal to 9.8.16.9.0, or 1,359,540 days. By way of a test, the number may be decomposed into its prime factors. It is found then to be equal to $2^2 \cdot 3^2 \cdot 5 \cdot 7 \cdot 13 \cdot 83$. This cluster of basic Maya primes marks it indubitably as a contrived interval. It is an integral multiple of the almanac ($2^2 \cdot 5 \cdot 13$), the glyph *G* cycle (3^2), the computing year ($2^2 \cdot 7 \cdot 13$), the triple almanac ($2^2 \cdot 3 \cdot 5 \cdot 13$), the 819-day cycle ($3^2 \cdot 7 \cdot 13$), and some of the compound cycles that required attention earlier, such as the 1,820-day period, the 2,340-day period, and the 3,276-day circuit. These, of course, are not all independent contributors to the interval, some being by-products of combinations of others. The almanac and the 819-day cycle alone would suffice to determine all but the last factor. Or the almanac, the computing year, and the cycle of the nine lords of the night would suffice for the same. The lowest common multiple of this collection of cycles is 16,380 days, equal to the day-count numeral 2.5.9.0, or in factor notation $2^2 \cdot 3^2 \cdot 5 \cdot 7 \cdot 13$. It was an important Maya number, equal to 20×819, of which a table of multiples must have been employed, together with one also of the first twenty multiples of 819 leading up to it, for the calculation of stations in the 819-day cycle. The remaining factor of 83 in the long interval is not basic to any of the Maya cycles, but was determined by the other principal requirement of a ring-number base, namely, that it be the last possible day in the old era, before the beginning of the new, that would satisfy the pertinent cyclical desiderata for the case in hand. These, in the present case, appear to have been that it have the same position in the almanac (*8 Ahau*), that it be under the same lord of the night (*G8*), and that it have the same location in the 4×819-day cycle (20 days after a "south" station in that cycle). These are three of the four principal attributes of a day, other than the lunar data, that accompany its day number in an initial-series passage at Palenque. But such a date has ascribed to it also an event. In the Temple of the Cross the old-era date of 12.19.13.4.0 (equal to −6.14.0 in respect to the current era) is declared to be the date of the birth of a female deity, an apparent mother-goddess and the implied ancestress of the royal line of Palenque. The likeness in kind between this date and the date of Pacal's birth has obvious implications. One's destiny was intimately related to the day of one's birth (this is amply documented throughout Mesoamerica from immediate postconquest times virtually to the present, and in some parts of the area both gods and men carried the name of the almanac day on which they were born as a principal component in their own names). The common attributes of the birth dates thus imply common attributes in the personages. The initial date of the temple appears thus to provide calendrical and numerological charter attesting to the legitimacy of the position of the ruler and of the dynasty that he founded.

This is not the only piece of numerology based on the number 2.5.9.0 at Palenque. The mother-goddess had a consort who was born shortly before her, at −8.5.0. Of their progeny, the second generation of gods and more or less triplets, one was born at 1.18.5.3.2 (as recorded in a further passage in the inscription of the Temple of the Cross), one at 1.18.5.3.6 (recorded in the first two passages of the inscription of the Temple of the Sun), and one at 1.18.5.4.0 (in the first two passages in the Temple of the Foliated Cross). The firstborn of these was the namesake of their sire, but the lastborn—a snake-footed deity—is the one who is calendrically and numerologically identified with him. (A scepter in the image of this deity became one of the principal symbols of authority at Palenque and at several other sites.) The interval from −8.5.0, which is the birth date of the sire, to 1.18.5.4.0, the birth date of the lastborn, is equal to 1.18.13.9.0, or 278,460 days, or $2^2 \cdot 3^2 \cdot 5 \cdot 7 \cdot 13 \cdot 17$. Here again are the factors of the Maya number 2.5.9.0, of which this interval is its seventeenth multiple.

The remaining birth dates of the second generation appear to be numerologically contrived also, in different ways and according to different desiderata, but subject to a further common condition that requires all three of them to be very near to each other, and, according to an early but still credible hypothesis,[21] to be within the calendar year in which the equinoxes (or solstices) are for the first time reversed in comparison with their calendrical positions in the year of the beginning of the era. These pieces of numerology will be passed over here—the one because of less than full certainty about it (chance cannot be entirely ruled out), and the other because of the complexity of the hieroglyphic evidence on which the demonstration depends. It will suffice to note that the latter establishes a special relationship of similarity between Pacal's son and immediate successor and the secondborn of this trio of gods. Instead of this, a

simpler case from another inscription will provide the final example.

It will have been observed that the mother-goddess was some 760 years old at the time of giving birth to this brood. This happened before her "accession." A following passage in the inscription of the Temple of the Cross says that it was over two *baktuns*—some 800 years—between the date of her birth and the date of her "accession to rulership" on a day *9 Ik 0 Zac*. (The glyphic phrase for accession in this case is the same one that is employed in similar "birth to accession" statements, in later passages of the inscription, for historical rulers who acceded to power at normal ages for human beings. It should be noted also that female occupancy of royal title and office is not an anomaly at Palenque.) The *9 Ik 0 Zac* date is brought up again in an inscription from Temple XVIII, which records events in the life of a later ruler. The accession passage in this inscription states that it was 2.3.16.14 (a little over 43 years) from this ruler's birth to his accession, and that the latter event was 7.14.9.12.0 (something over 3,045 years) after the accession of the mother-goddess on *9 Ik 0 Zac*. The ruler's birth date is recorded in the initial series of the inscription as 9.12.6.5.8, *3 Lamat 6 Zac*. His accession date was 9.14.10.4.2, *9 Ik 5 Kayab*. That of the mother-goddess was 2.0.0.10.2, *9 Ik 0 Zac*. The Maya numeral that intervenes between these two accessions, 7.14.9.12.0, makes the interval equal to 1,112,280 days. Factored, this is $2^3 \cdot 3 \cdot 5 \cdot 13 \cdot 23 \cdot 31$, which contains the components of the almanac, the triple almanac (of possible relevance to Mars), and the Maya eclipse cycle (46 almanacs) as known from the much later Dresden Codex. It was not an eclipse date, however. The age of the moon is given in the initial passage as 19 days, that is, counted from appearance of the crescent (from conjunction it was approximately 22 days). Neither was it close to an eclipse season. The only apparent reason for an integral multiple of the 11,960-day eclipse cycle then is numerological. Something of the historical context can be sketched. An aging predecessor had either died or failed to rule to the end of his days (if dead, he was not yet buried). An also aging brother of his, five years his junior, was installed as successor a little over a year and a half before the date in question. Of this one there is no further record; he may not have lasted long, having been 71 years old when he replaced his brother. For whatever reason, quite possibly the death of the elderly recent successor, the time was at hand for the installation of someone of the next generation. Apparently an auspicious day was sought for the occasion, perhaps with some urgency in the face of a rival claim. None of the other good numbers when applied to an auspicious day of the past would produce one now, but this one did. It may have been seen as a safe place in the eclipse cycle and a good day in the almanac; but in any case, in this combination it had auspicious precedent in the accession of the ancient one. However good it may have looked, it was not good enough. This ruler's death is recorded as of a year later, and he was succeeded by another—six years his senior—in less than a year and a half after his own accession. In his successor's tablet he is treated rather curiously, as if an interloper.

VII. A TIME PERSPECTIVE

The earliest recorded dates that are indubitably Maya, and that are contemporaneous with the objects on which they are engraved, are at 8.12.14.8.5 and 8.14.3.1.12 in the day count. There are yet earlier ones recorded in the same count, also contemporaneous with their objects, going back as far as 7.16.3.2.13; but these are not "Maya" in any accepted sense of the term. The distinction hinges on several archaeological criteria and on the character of the associated hieroglyphs, whether these be in the tradition of Maya writing or in a different tradition, as well as on the question of whether there are reasons for assuming that the peoples who produced the objects were ethnically and linguistically ancestral to Maya peoples.

In order to put these dates and others into a more familiar frame of reference for history, it is necessary to adhere—at least with consistency if not yet entirely with conviction—to some one of the several hypotheses that have been advanced for a correlation between the Maya and the Christian chronologies. At an earlier point in this review, in section III, the need arose for approximate translations of Maya dates, and use was made of a correlation characterized there as "accepted by some." That was the one commonly known as the Goodman-Martinez-Thompson correlation, which is not just one, but is a family of successive revisions within a six-day range, positing from 584,280 to 584,285 as the number to be added to a Maya day number to convert it to the equivalent Julian day number. It began as a historically based correlation (rather than as an astronomical one), resting

on interpretations of evidence in documents of the postconquest period. Goodman's original conversion figure was 584,280. At the present point in the understanding of the problem, the favored alternatives within this set are 584,283 (Thompson's third and last revision) and 584,285 (his first).

The greater of these, preferably increased by yet another day, is the only one of this set that would be consistent with the interpretation of moon ages and of dates in the eclipse table that has been presented here. Employment of this correlation will be continued in what follows, but it will not be carried to the point of specifying the precise day that is implied for each Maya date. These equations with Christian years should be regarded as tentative. If untrue, perhaps they are not so grossly untrue as seriously to distort the temporal relationships between Mesoamerican and Old World history. Most archaeologists at the present time are satisfied that the Goodman-Martinez-Thompson correlation provides dates that are suitably within the ranges established by their methods. Some others who have concerned themselves with the correlation problem, however, will wish to see a greater antiquity in the day-count dates than is given to them here.[22]

By this correlation the two early Maya dates cited above are from the years A.D. 292 and A.D. 320. If Maya "history" is to be counted from its oldest chronicles of events, then it begins with the accessions of two rulers in these years, the earlier from the ancient city of Tikal (in the Peten of present-day Guatemala), and the other from some location in the same sphere of cultural influence. The earlier record is on Stela 29 of Tikal; the second is on a small celt-shaped jadite pendant known as the Leiden Plaque (after the city in whose ethnographic museum it is preserved). The inscription of the Leiden Plaque has an "initial-series introducing glyph" that anticipates the classic form, having three of its four classic constituents, including the variable part appropriate to the month named further on in the series. It has bar-and-dot numerals prefixed to head-form period signs for the five orders of units in the day number (*baktuns*, *katuns*, *tuns*, *uinals*, and *kins*). And it has the proper almanac day, glyph *G*, and year day. But it has no lunar data. The full specification of the date is "8.14.3.1.12, *1 Eb*, G 5, *0 Yaxkin*." The date is followed by an accession statement, with the "seating" glyph and the name of the ruler who was seated on that date and who is depicted in symbolic regalia on the front side of the plaque. It is worthy of note that already in this second-earliest surviving Maya inscription the twentieth day of a month is designated as the day of the seating of the following month (transcribed as *0 Yaxkin*), and that the seating sign appears twice, with appropriately different suffixes, in two of the uses which it has in later inscriptions: for the seating of months and for the seating of rulers. (In the latter function it is one of five different but more or less synonymous glyphic expressions used in Classic Maya inscriptions for the installation of rulers.) Stela 29 of Tikal, despite its difference in size, is similar in composition as far as it is preserved, including the depiction of a ruler in his symbolic vestments on the front side; but the bottom portion of the stela is missing, being broken off just beyond the day number and through the trecena number of the almanac day. It is probable that this inscription was of a length and form comparable to that of the Leiden Plaque. The hieroglyphs in both inscriptions are of Maya form.

The day count, the 260-day almanac, and the 365-day year divided into twenty-day "months," all have a history that antedates their Maya use.[23] There are at least four pieces—one from Chiapas, two from Vera Cruz, and one from the southern highlands of Guatemala—that have earlier dates in the day count. The earliest (Stela 2 of Chiapa de Corso, Chiapas) is at 7.16.3.2.13, which would be in the year 36 B.C. by the correlation employed here. The next (Stela *C* of Tres Zapotes, Vera Cruz) has the date 7.16.6.16.18, corresponding to 31 B.C. Another (Stela 1 of El Baul, Guatemala) is at 7.19.15.7.12, which is in the year A.D. 36. The fourth (the Tuxtla Statuette, from San Andrés Tuxtla, Vera Cruz) has 8.6.2.4.17, in the year A.D. 162. Thus the day count was already in use for at least 328 years before the earliest surviving record of it that can be identified as Maya, and had quite a wide geographic distribution. All four of these earliest surviving instances employ bar-and-dot numerals. None of them employ signs for the periods, depending simply on place notation. In this they differ from the Classic Maya usage, but conform to that which appears again in the post-classic Dresden Codex. Thus the use of place values in numerals appears to precede the more explicit graphic expressions from which the convention might otherwise be assumed to have been derived. All four of the inscriptions specify the almanac days, and in these, all of them employ signs for the days in the veintena that are quite

outside of the Maya tradition of day signs. In three of them, the almanac day follows the day number, but in one (El Baul) it precedes it. None of the four, so far as can be known, specified the year days; although because of breaks in two of the pieces the negative evidence is lacking in these. Two pieces (Stela *C* of Tres Zapotes and the Tuxtla Statuette) exhibit early forms of the "initial-series introducing glyph," even though neither of them has the chronological series that is so introduced in a position which is initial to the inscription. (It might thus better be called a "day-number introducing glyph.") Both introducing glyphs have a tripartite superfix similar (one very much so, and one somewhat less so) to that which is a standard part of this glyph in Classic Maya inscriptions. They also have instances of the "variable element" in them, one definitely and the other possibly corresponding to the appropriate calendrical twenty-day "months." Thus the introducing glyph, in at least two of its standard components, is pre-Maya. The inclusion of a variable element, especially the identifiable one in Stela *C* of Tres Zapotes, implies that the vigesimally based subdivisions of the calendar year were already instituted, even though they are not named in separate year-day specifications as they are in Maya inscriptions.

The 260-day almanac and the 365-day year, as well as bar-and-dot numerals, have a still older history. Inscriptions from the Valley of Oaxaca give evidence of these as far back as about the middle of the first millennium B.C. In these inscriptions, bar-and-dot numerals for days in the trecena accompany signs for days of the veintena; but they follow them, being written immediately below the day signs, rather than preceding them as prefixes or as superfixes as in all later usages. These inscriptions give evidence of the 365-day year by naming years for their "year bearers," the almanac days on which they begin. These, restricted to four days of the veintena, but combining with all positions in the trecena, name the 52 years of the calendar round and fix dates within this cycle. This is a practice for which there is no evidence in Classic Maya inscriptions, but for which there is good evidence in all three Maya codices (Dresden, Paris, and Madrid), as well as in Central Mexican sources, and which was very much in evidence in Yucatan and elsewhere at the time of the conquest and until recently. It is an element of Mesoamerican calendrical practice which has had a history of approximately two and a half millennia. It is uncertain whether the Oaxacan inscriptions give evidence for vigesimally based subdivisions of the year. Numerals higher than thirteen in certain contexts have suggested that possibility, but they are open also to other possible interpretations.

The early history of the Mesoamerican numerical and calendrical usages may be outlined roughly as follows, where the dates refer to the *earliest* reliable attestations of each usage. The first two groups of items are pre-Maya; after A.D. 292 they are Maya.

ca. 500 B.C.: Bar-and-dot numerals
260-day almanac
365-day year
Year-bearer names for years

36/31 B.C.: Day-count chronology
Place notation in numerals
Day-count introducing glyph
20-day months

A.D. 292/320: Period signs
Year days (month and day)
9-day cycle of Glyph *G*

A.D. 357: Lunar data

A.D. 668: 819-day cycle

The earliest secure evidence for the recording of lunar data is in an inscription from Uaxactun (north of Tikal), bearing a date of 8.16.0.0.0, which would place it in the year A.D. 357. It records a moon age (25 days), a position in the half-year (no. 1), and a duration (29 days). The lunar calendar, including a concept of lunar half-years (presumably eclipse half-years), and the classic pattern for recording lunar data were thus established before this date. The moon age was apparently reckoned from appearance of the crescent, for an attempt to reckon from conjunction would have yielded an age of 27 days for this date. It is possible that the lunar calendar and the concept of half-years were considerably older than this date. There is an early polychrome vase, also from Uaxactun, which has a recorded date with seven *baktuns* and which also records a moon age, moon number in the half-year, and a moon duration; but the date is inconsistent both with the lunar data and with the calendar-round position ascribed to it. If it really was from before the completion of eight *baktuns*, then the origin of the lunar calendar, with its half-years and the pattern for recording lunar data,

would have to be attributed to a time prior to A.D. 42.

The 819-day cycle apparently did not enter the picture until about the middle of the classic period. The earliest evidence for it is from Palenque (Chiapas) in a stucco glyph panel commemorating an event in the life of the ruler Pacal in 9.11.15.15.0, which would be in A.D. 668. The panel may have been placed there later, but probably no later than the next *katun*-ending, 9.12.0.0.0, or A.D. 672. The 819-day station was 9.11.15.11.11. An earlier one, also from Palenque (the Palace Tablet), is at 9.10.10.11.2 for an initial date of 9.10.11.17.0; but the panel records history up to 9.14.4.8.15 and was probably erected or dedicated about half a year later, at 9.14.5.0.0, in A.D. 716. There are earlier stations recorded, going all the way back to mythological antiquity (the earliest being 6.15.0 before the current era), but they are on monuments erected no earlier than 9.13.0.0.0. The last one known is at Quirigua (Stela *K*) with a station at 9.18.14.7.10 for an initial as well as dedication date of 9.18.15.0.0, in A.D. 815. The interest in this cycle, late to become manifest, appears thus to have lasted for only a century and a half. Only fourteen examples of it are known to the writer: eight from Palenque, three from Yaxchilan, two from Copan, and one from Quirigua.

The 405-lunation eclipse cycle, of 11,960 days, is known principally from the Dresden Codex, which is estimated to be from the late twelfth or early thirteenth century. The codex, however, is a copy or new recension of an earlier work. The prototype of that eclipse table may be assumed to belong to the epochal date 9.16.4.10.8, in A.D. 755, when its final *12 Lamat* was about fifteen days prenodal. The version appearing in the codex, however, is assumed to be from nine or ten eclipse cycles later, 10.11.3.10.8 or 10.12.16.14.18, in A.D. 1050 or 1083, when the then final *12 Lamat* was approximately at a node or at most a day postnodal. The earlier of these two possibilities, A.D. 1050, appears more likely at present. The bottom line of almanac days with a *13 Muluc* base, and the eclipse interval of 26,519 days from the *13 Muluc* date of 9.12.10.16.9 (represented as a ring-based day number, −12.11 + 9.12.11.11.0, on page 58 of the codex) to the *12 Lamat* date of 9.16.4.10.8, suggest knowledge of the eclipse cycle going back at least to 9.12.10.16.9, or A.D. 683. The eclipse cycle was employed at Palenque in a piece of numerology (in Temple XVIII, described here in section VI) to determine the accession day of a ruler. That accession day was 9.14.10.4.2, at the beginning of the year A.D. 722. The cycle was employed in another piece of numerology also at Palenque (in the Temple of the Sun, to which reference was made in section VI but which was not described there); and the so-called Palenque moon ratio of 81 moons to 2,392 days, which was used to predict moon ages for the mythological dates of 1.18.5.4.0, 1.18.5.3.6, and −6.14.0, is nothing more than the ratio in the eclipse cycle, of 405 moons to 11,960 days. The dedication date of the temples in which these appear was 9.13.0.0.0, or A.D. 692. It is thus clear that the eclipse cycle was fully formulated by the last decades of the seventh century A.D.

There is a question as to how much earlier it may have been known. The numbering of moons in half-years that are never greater than six months in length suggests that knowledge of eclipse seasons may be as old as that practice, which would put it back to before A.D. 357. But knowledge of seasons should not be equated with knowledge of the cycle. The earliest definite evidence for the latter is from A.D. 683 or 692.

The so-called period of uniformity in regard to moon numbering, with its inflexible six-month half-years from 9.12.15.0.0 to the beginning of its demise about 9.16.5.0.0, or roughly from A.D. 687 to 756, is a curious interlude in a period when the length of the cycle and the nature of its subdivisions must already have been well known. It was pervasive while it lasted; but its dominance was broken within seventy years. A reformulation of the arrangement of divisions, subdivisions, and half-years in the eclipse cycle appears to have been under way before 9.16.4.10.8, the Dresden Codex epochal date. At Yaxchilan a stela with an initial date of 9.16.1.0.0 (A.D. 752) has its date and its lunar data recorded twice, with the latter according to two different interpretations. On the side of the stela it is given with a moon number agreeing with what that date should have according to the uniform system (moon age 12 days, moon number 5, duration 30 days), but on the front it appears in the new interpretation (moon age 12 days, moon number 4, duration 29 days). The fact that the moon duration also differs in the new interpretation gives additional evidence that a new lunar calendar was being inaugurated. The moon number "4" in this interpretation is possible only if the last division of the eclipse cycle just prior to 9.16.4.10.8 was one of 47 months (or more), that is, seven (or more) half-years of six months and one of five months, and further, only if glyph *C*, the moon number, is the

ordinal number of the current moon. There is no possibility that the moon number here can refer to the number of completed moons in the half-year. Whether this was a new interpretation of moon number in relation to that of the preuniform period cannot yet be known; but it was new, at least in one respect, in relation to the concept of moon number held during the period of uniformity. As for moon age, both recordings of this inscription give witness to an attempt to reckon it from a hypothetic conjunction (overshooting it, apparently, by something over half a day). It cannot have been reckoned from visibility of the crescent.

The discovery of the calendrical method for more refined long-range lunar computations, with compensation for the small error (about one-ninth of a day in the length of the eclipse cycle) as it is multiplied by repetition through long periods of time, cannot be dated with any certainty, because it is not known whether the late dates involved in its application were contemporary, already in the past, or were predictions into the future. This last, however, is least likely. Exclusion of this hypothetic possibility, if it be a cause of error, will result in error only on the conservative side, in not risking ascription of dates that may be too early. If the latest of the *3 Chicchan* dates discussed in section V is taken as a guide (10.7.4.3.5), the discovery might be placed at, or after, A.D. 972. If the latest of the set of dates in the codex that contains this be chosen (10.11.5.14.5), then it would be A.D. 1052 or thereabouts, which is just two years after the most probable epochal date of the eclipse table in the form which it has in the Dresden Codex, with its *12 Lamat* base at a nodal position in the cycle. If the latest date recorded in the Dresden Codex, another *12 Lamat* (10.19.6.1.8), which also may represent an application of the compensation method (it is five almanacs less than five eclipse cycles after the probable epochal date of the codical version of the table), then the date would be A.D. 1210, or not long thereafter, that is, about the presumed time of the codex itself.

If 10.11.3.10.8, in A.D. 1050, be the epochal date for the current version of the eclipse table, then it is quite in line for 10.10.11.12.0, in A.D. 1038, to have been the epochal date for the current Venus table, as was posited in section IV and as is most generally accepted. That was the date *after which* corrections to the Venus cycle were applied by periodic foreshortenings of the cycle in order to find a new base at the foreordained place in the almanac.[24] There is a notable similarity between the Venus corrective device, instituted as of 10.10.11.12,0, with its 13.0.0 and 6.9.0 foreshortenings (eighteen and nine almanacs respectively) preserving its *1 Ahau* base, and the corrective device for the eclipse and lunar-reckoning table, with periodic foreshortenings in amounts of 7.4.0 or 3.11.0 (ten and five almanacs respectively) preserving its *12 Lamat* base. They employ a common strategy, and may well have been products of the same school of calendrical astronomy, and of about the same time, in which case the invention of the latter would most plausibly be ascribed to the epochal date in the year A.D. 1050. The two current epochal dates, of the Venus table and of the eclipse and lunar-reckoning table, are within twelve years of each other. Before that time, a shifting base, allowing one-day foreshortenings of the cycle as needed, must be assumed for the eclipse table. This is in agreement with the interpretation given in section V to the three successive lines of almanac days in that table.

The Mesoamerican day count, which was in use as early as 36 B.C., disappeared also early from the non-Maya and from the highland Maya areas, and its continuation was principally in the hands of the lowland Maya peoples. It did not survive, however, to the coming of Europeans. (If it had, there would be no "correlation problem.") The last stone monuments erected with dates in the day count were 10.3.0.0.0, in a year that we are supposing to be A.D. 889. The last surviving use of the count engraved on stone was on a jade piece with the date of 10.4.0.0.0, in A.D. 909. But the count was still employed in other media, at least until the time of the compilation or copying of the Dresden Codex, whose last recorded date—presumably more or less contemporary—was 10.19.6.1.8, in A.D. 1210. There is no further trace of it, although employment of its numerical system persisted in other contexts. The day count had by this time been superseded by a method that grew out of one that had coexisted with it almost from the beginning of the Maya use of the count. This was the one exhibited in the anchoring of secondary dates, by relating them to period-endings—principally *katun*-endings—as described in section III. So long as the complete calendar-round specification of a period-ending was employed, including its positions in both the almanac and the calendar year, the resulting specification was unique and unambiguous within a span of 18,720 calendar years, or 18,980 chronological years. But the naming of *katuns* by their ending days came to

be abbreviated—even sporadically in inscriptions of the classic period—to include just the name of the almanac day. Suppression of the year day from the *katun* name became general at sites in the peninsula of Yucatan by the late decades of the ninth century A.D. The *baktun*, *katun*, *uinal*, and *kin* numberings were dropped. Of the five orders of units enumerated in a classic day number, only the *tuns* (the chronological years) continued to be numbered within the *katuns*. The *katuns* were known by their terminal *Ahaus* with trecena coefficients (diminishing by successive decrements of 2 as described in section III). And the days were specified by their positions in the calendar round, for which the year-day positions as well as the almanac days were still used. This system of characterizations apparently served adequately, according to the colloquial manner that had developed in the spoken language, for chronological orientation and for the record of historical events; and it is possible to translate such dates back into the day count. For example, a date in this manner, repeated three times in inscriptions at Chichen Itza, is expressed as: "Nine Lamat the day, on the eleventh of Yax, in the course of the thirteenth tun of One Ahau (*katun*)," which is equivalent to 10.2.12.1.8, *9 Lamat 11 Yax*, in the classic manner of statement.[25] The year is A.D. 881. Dates expressed in this late manner have the same degree of specificity as had those related by distance numbers to fully expressed period-endings, that is, they are unique within a cycle of 18,720 calendar years, or 18,980 chronological years, which is equivalent to 360 calendar rounds, or 949 *katuns*, or 2.7.9.0.0.0. The earliest date in this manner was from A.D. 743. The rest are from between A.D. 867 and 916.

By the end of the classic period the day count was on its way to abandonment, at least for civil use and commemorative records and monuments. In the hands of the astronomers, however, it survived for some time. Its last recorded date in the Dresden Codex, from A.D. 1210 (we are presuming), has already been mentioned. It may have been understood, and possibly even used, by copyists and possessors of codices into later times, but no record survives to give evidence. The Paris Codex, believed to be of only slightly later date than the Dresden, has interscribed numbers in various colors, several of them five positions in length. It cannot be shown that these are dates, but they are quite certainly intervals, some of them apparently with astronomical import. The Madrid Codex, estimated to be a product of the mid-fifteenth century, has a single instance of what may be a five-place numeral (with ten *baktuns*), but again there is no assurance that it is a date. One can only wonder how much of the chronological and astronomical content of the Dresden Codex was understood by its last Maya possessor. What survived of the chronological system after that, in the postconquest conflations of history and prophecy known as *Books of Chilam Balam* (written in romanized Maya), is the naming and ordering of the *katuns* by their numerically qualified *Ahaus*, with occasional additional precision lent by placements of dates either in the almanac or in the European calendar and Christian years.

The 260-day almanac survives today in some parts of Mesoamerica, not only in certain Maya communities, but also in a few of other linguistic areas. In no place is it common knowledge, but is the more or less guarded knowledge of religious specialists, curers, and diviners. The 365-day year calendar, with its twenty-day months and five-day residue period, also survives in some communities both within and outside of the Maya area. But in the years immediately following the conquest this became anchored to the European calendar, so that its days no longer drift through the seasons. Its anchoring is not by conscious intercalation of a day in leap years, but rather by equating a particular day of their calendar year with a local patron saint's day in the Roman church calendar, the fixing of which is out of their control. These anchorings may have taken place at different times in the early postconquest years, since there is variability in amounts up to a week or more in the equations of the native calendars with the European calendar from one community to another. There is also variability as to where the five-day residue is inserted into the sequence of the eighteen months. Knowledge of the year calendar, where it survives, is more public and less guarded than knowledge of the almanac is in its places of survival. There are few if any communities where both are still known. Where the almanac survives, it represents an almost unbroken continuity from the ancient past. Their agreements are very close, to within a day or two when not to the precise same day, even in widely separated areas. The implication is that there has been very little of losses or slippage during the more than two millennia of its existence.

The outline of early history of Mesoamerican numerical and calendrical usages tabulated earlier in this section, extending from *ca.* 500 B.C. to A.D.

668, can be supplemented now with the following outline of later developments:

A.D. 683/692: Early evidence for knowledge of eclipse cycle

687: Beginning of period of "uniform" moon numbering, in disregard of eclipse seasons

752: First evidence for reformulation of lunar calendar

755: Epochal date of eclipse table with 15-day-prenodal *12 Lamat* base (9.16.4.10.8)

756: Beginning of abandonment of "uniform" system of moon numbering

815: Last recognition of 819-day cycle

867–916: Dates in the "Yucatecan" method (an isolated early example in A.D. 743)

889: Last stone monuments with dates in the day count (10.3.0.0.0)

909: Last smaller object (jade) with inscribed date in the day count (10.4.0.0.0)

1038: Epochal date for Venus table as appearing in Dresden Codex (10.10.11.12.0)

1050: Probable epochal date of eclipse table as appearing in Dresden Codex, with approximately nodal *12 Lamat* base (10.11.3.10.8)

1129: First application of corrective device for Venus calendar (10.15.4.2.0)

1210: Latest day-count date recorded in Dresden Codex (10.19.6.1.8)

1536: First anchoring of Maya calendar year to European year

Today: Sporadic survivals of 260-day almanac and of Maya 365-day year with 18 twenty-day "months" and five-day residual period

It is perhaps superfluous to add that this should be taken as no more than one person's attempt at a chronology of developments in Maya calendrics and astronomy, that it is incomplete in many respects, and that the dates rashly ventured here are held subject to revision.

NOTES

1. The primary historical source from the early colonial period is Diego de Landa's *Relación de las cosas de Yucatán* (*ca.* 1566), Tozzer, translator and annotator (1941).

   Sources for Maya inscriptions are too numerous to be listed here. The principal collection has been Maudslay's *Archaeology* (1889–1902). The compilation of a *Corpus of Maya Inscriptions* has only recently been inaugurated, and four installments, by Graham and Von Euw (1975, 1977), have appeared. For other sources, see the list and the references at the end of Thompson's *Catalog of Maya Hieroglyphs* (1962), 404–424.

   The codex that is our principal source for Maya astronomical knowledge is that of Dresden. For its history, and for a description of the codex and its various published editions, see the essays by Deckert and Anders that accompany *Codex Dresdensis* . . . (Graz, 1975). See also the essay by Thompson (1972), 3–27, accompanying his edition and commentary. The first publication of the Dresden Codex was by Lord Kingsborough (1831), after drawings by Agostino Aglio, printed and hand-colored. The editions by Förstemann (1880, 1892; reissued 1964) are the only photographically based color reproductions of the codex in its condition prior to water damage suffered during World War II. The edition by Villacorta and Villacorta (1930; reissued 1976), which includes also the Paris and the Madrid Codices, is from black-and-white hand-drawn copies of photographs that are remarkably true to the originals. The Venus and the lunar tables reproduced as figures in the present essay are from that edition. The edition by Gates (1932), in color, is no attempt at facsimile rendition but is a complete recasting in Gates's own personal but very legible style of drawing. Thompson's edition (1972) is from recolored black-and-white photographs of Förstemann's 1892 edition. The "Graz" edition, *Codex Dresdensis* . . . (1975), in color, is from photographs of the codex in its present damaged state. A slightly retouched reprint of the Villacorta drawings accompanies it, offering a comparison and compensating for details now lost. The essays by Deckert and Anders, cited above, are in the volume that contains this reprint.

   The Paris Codex, known also as Codex Perez or Codex Peresianus, was published by de Rosny (1887, 1888), Gates (1909), Villacorta and Villacorta (1930), and by the Akademische Druck- und Verlagsanstalt of Graz (1968). There are editions of the Madrid Codex, known also as the Codex Tro-Cortesianus, by Brasseur de Bourbourg (the Troano portion, 1869–1870), de Rosny (the Cortesiano portion, 1883), de la Rada y Delgado (the Cortesiano portion, in color, 1892), Villacorta and Villacorta (1930), Gates (black-and-white photographic, 1933), and the Akademische Druck- und Verlagsanstalt (color photographic, 1967). Fragments of eleven pages from a fourth codex, containing a portion of a Venus table, have been published by Coe (1973), 150–154.

2. The Cachuianã numerals are from Vinhaes (1944), 197–202. The Bororo examples are from Colbacchini and Albisetti (1942), 282–283, Rondon and Faria (1948), 25, Albisetti and Venturelli (1962), 1, 800–801, 866–870, and from the author's field notes. Iroquois information derives from the author's field studies. Two of the important Yucatec Maya sources are Beltrán de Santa Rosa (1746, 1859) and Pío Pérez (1866–1877). For the numerous other sources on Yucatec, as well as on the other languages of the Mayan family, see the *Bibliography of Mayan Lan-*

guages and Linguistics compiled by Lyle Campbell and collaborators (in press). An early collection of comparative data on Mayan and other Mesoamerican numeral systems, both verbal and graphic, is by Thomas (1900).

3. In the citation of Yucatec Maya forms it has been necessary to choose between fidelity to the sources quoted and fidelity to the known character of the language. The latter would have required *hoo* and *caa* in several of the cited examples, or retranscription of them as *ho'* or *ho'o* (depending on context) and similarly *ca'* or *ca'a*.
4. Of the numerous introductions to Maya calendrics the following should be mentioned: Bowditch (1910), Teeple (1930), 33–64, and Thompson (1950), 66–262.
5. LaFarge and Byers (1931), 157.
6. The spellings employed here for the Yucatec month names are those from Landa's *Relación de las cosas de Yucatan* (*ca.* 1566; see Tozzer [1941]). Although they are inadequate in many respects as transcriptions of Maya, they are traditional and serve well enough as labels for calendrical entities and for the hieroglyphs named by them. The writer sees no point in applying halfway corrective measures to their spellings, as some have done, when the resulting forms are still faulty anyway. A linguistic treatment of the terms is beyond the scope of this essay.
7. The determination of the values of the glyphs of the "supplementary series" is an interesting chapter in the history of decipherment. The lunar character of a portion of the series was anticipated by Morley in 1916 and the significance of glyphs *A* and *C* was recognized. The meanings of glyphs *D* and *E* were determined by Teeple (1925). The significance of glyphs *G* was apprehended by Thompson in 1929, when he determined that they were essentially a set of nine (although with variants) and discerned in them a Maya analogue to the nine Aztec lords of the night. The 819-day cycle was discovered in 1943, also by Thompson. Additional attributes of the cycle were determined by Berlin and Kelley (1961), and further examples of its representation in inscriptions have come to light since then. (See references in Bibliography.)
8. The first demonstration of historical content in Maya inscriptions was by Proskouriakoff (1960); see also (1961), (1963), and (1964). Prior to her discoveries a prevailing view among Mayanists was that the inscriptions focused on the "journey of time" as an object of religious veneration; cf. Thompson (1950), 64–65, 155. A wholly erroneous view prevailed concerning the function of the "secondary series," that is, of passages containing dates and distance numbers within a text; see Morley (1946), 289–291. This derived from one of the few serious errors in Teeple's remarkable work, his theory of "determinants" (1930), 70–85; see also Thompson (1936) and (1950), 317–320. In spite of the now demonstrable and predominant historical content in the inscriptions, it must still be granted that the Maya concern with time was in some considerable part a religious matter. Even in modern times the twenty named days of the veintena, or the 260 of the almanac, have been regarded as deities and addressed in prayers of supplication; see La Farge and Byers (1931), 153–173.
9. La Farge and Byers (1931), 158.
10. See Bowditch (1910), 324–331.
11. Cf. Bowditch (1901), Zimmermann (1935), Lizardi Ramos (1939), and Thompson, *Maya Arithmetic* (1941).
12. Important previous studies of the Venus tables are by Teeple (1930), 94–98, and Thompson (1950), 217–229. It was Teeple who discovered the significance of the alternative bases and the nature of the corrective procedures. Barthel (1952) has dealt with the iconography, hieroglyphs, attributes of the deities named in the table, and the structural relations symbolized by them.
13. Unavoidably the "period" mark is employed in two different senses in the punctuation of numerals, depending on whether it appears in a Maya or an Arabic numeral. In the columns headed "Error in Days" and "Residual Error" it is the decimal point, whereas in the second and third columns it is a place divider for Maya numerals. Elsewhere the context of the numeral or the magnitudes of its parts suffice to make clear the nature of the numeral and the interpretation of the period.
14. Some previous studies and commentaries on this table are those of Förstemann (1906), 200–215, Meinshausen (1913), Guthe (1921), Willson (1924), Teeple (1930), 86–93, Makemson (1943), 187–208, Satterthwaite (1947), 142–147, and Thompson (1950), 232–236; (1972), 71–77; (1975), 88–90. A brief review of contributions prior to 1950 is given in Thompson (1950). Teeple's study is of particular importance. It was he who first isolated the nodes of the table and who posited the method by which the Maya might have defined the eclipse seasons. Meinshausen's paper is important for its demonstration of the role that observations of lunar eclipses could have had in the construction of the table.
15. See Aaboe (1972) for apparent instances of employment of a 135-lunation cycle in the prediction of eclipse possibilities in ancient Old World astronomy.
16. See Willson (1924) for an account of the testing of this hypothesis.
17. The ecliptic limit for solar eclipses varies between a minimum value of 15.4 degrees and a maximum value of 18.5 degrees; that for lunar eclipses varies between 9.5 and 12.1 degrees; see Smart (1965), 398. For present purposes, "degrees" (of the earth's angular distance in its orbit from a node) may be translated approximately into "days" by multiplying these figures by 0.96 days per degree.
18. See Makemson (1943). A somewhat distorted version of Makemson's hypothesis is attributed to her by Thompson (1950), 234; and (1972), 73.
19. The possibility of this method of correction was anticipated by Thompson in 1950 and was developed in 1972 and 1974, but only in respect to the five-almanac foreshortening which is not applicable to eclipse reckoning. See Thompson (1950), 235–236; (1972), 74–75; (1974), 89–90.
20. For fuller treatment of ring numbers and ring-based day numbers in the Dresden Codex, and of two of the Palenque cases described here, see Lounsbury (1976). Other instances of Palenque numerology are not yet in print.
21. Bowditch (1906).
22. For reviews of the correlation problem see the following, listed chronologically: Teeple (1930), 104–109, 115; Thompson (1935); Andrews (1940); Thompson (1950), 306–310; Satterthwaite and Ralph (1960); Satterthwaite (1965), 625–631; and Kelley (1976), 30–33. Further bibliography pertinent to the numerous proposed correlations will be found in these.

    It will be observed that the interpretations of the eclipse and Venus tables put forward in the present essay, as these affect the correlation problem, are more in accord with Thompson's views than with any of those that are seriously at variance with his. For example, see criteria nos. 6, 7, and 8 in the review by Kelley. In the matter of reckoning moon ages, however, the interpretation here concurs better with Thompson's earlier views (1935) than with his later opinion (1950), 310, or with Satterthwaite's (1965), 629–630. The historical problem that motivated their shift to a 584,283 correlation constant, and to a reevaluation of the meaning of moon ages, appears now to have another resolution and is less compelling.

    The suggested one-day increment to Thompson's first constant, giving 584,286 rather than 584,285, has the advantage that it permits acceptance of the best apparent candidate for the recording of a solar-eclipse observation on a stone monument. The item came to Teeple's attention only in time to be noted in a one-page addendum to his *Maya Astronomy* (1930). The event, recorded on Stela 3 of Santa Elena Poco Uinic, Chiapas, Mexico, is dated

9.17.19.13.16, which is day number 1,425,516 in the Maya count, and would be JD 2,009,802 or July 16 (Julian) A.D. 790 by the 584,286 hypothesis. This is the date of eclipse no. 4768 in Oppolzer, a total eclipse whose path of centrality swept across this precise location and whose conjunction time was approximately 48 minutes after 12:00 noon, local time at 91.8 degrees west longitude. The record is on a katun-ending monument with initial date 9.18.0.0.0, which records events of the preceding period concerning the local ruler. These are badly eroded, so that neither their precise dates nor their nature can be established; but the last event, the presumed eclipse, with both its glyph and its distance number connecting it to the initial date, is well preserved due to having been below ground. It has still to be proven, however, that the glyph designating this event is indeed a "solar eclipse" glyph. It has the "sun" sign flanked by a pair of over-arching appendages, the arrangement being formally similar to that of the eclipse glyphs of the codices, and the flanking appendages having the form of the principal element of glyph *B* of the lunar series that accompanies initial dates of monumental inscriptions.

A disadvantage, not only of the 584,286 hypothesis but of the entire Goodman-Martinez-Thompson set of alternatives, is that it requires all of the apparent "eclipse" dates of the Dresden Codex to be products of computation rather than records of observation. Neither the *12 Lamat* date 9.16.4.10.8 nor the *13 Muluc* date 9.12.10.16.9 would have been eclipse dates by this correlation, although both would have been half a month prior to dates of total lunar eclipses, and one month prior to partial solar eclipses. Thus, of the three dates on page 52*a* of the Dresden Codex that are separated by fifteen-day intervals, the first would not have been an eclipse date; the second would have been within about half a day of a lunar eclipse, but one visible only in the eastern hemisphere; and the third would have been within a day of a partial solar eclipse, but one not visible in Central America. As attempted computations of eclipse-possible times, however, all of them are reasonable.

The great strength of the Thompson correlation lies in its accommodation of data from postconquest historical sources as well as twentieth-century survivals of the almanac, while still accommodating computational if not observational astronomy.

23. For more detailed reviews of the early dated monuments see Coe (1957) and (1976), and Marcus (1976). Acceptance of the evidence for the pre-Mayan dates was slow in coming: compare the earlier views of Morley (1946), 41, and of Thompson, *Dating of Certain Inscriptions* (1941), in regard to these monuments, and in particular in regard to the reconstruction by Stirling (1940) of the 7-baktun date of Stela C of Tres Zapotes. Any lingering doubts were laid to rest in 1973 with the discovery of the missing portion of that stela, with seven baktuns, as had been predicted from the trecena number together with the lower four places in the day number, thus proving the correctness both of the date and of Stirling's assumption that it belonged to the same day count as do Maya dates.
24. The first such application was toward the end of that Venus great cycle, on 10.15.4.2.0, in A.D. 1129.
25. The decipherment of dates expressed in this manner was by Thompson (1937); see also (1950), 197–203.

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